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ECL-41

HUGHES TOOL COMPANY, AIRCRAFT DIVISION (A)

Development of a Light Observation Helicopter for the United States Army

In early 1960, Mr. Herbert Lund, a Project engineer at the Hughes Tool Company in Culver City, California, faced the task of developing design sketches for a new gas turbine powered helicopter. Overall size and performance objectives had been dictated by the customer, the U. S. Army. Mr. Lund and his colleagues had also made basic decisions concerning the engine, rotors, and some of the basic dimensions. It would be necessary to integrate consideration of these constraints and objectives in the sketches which would then serve as the basis for construction of wind tunnel models and full-sized mockups.

When Hughes Tool Company decided to enter the competition for the helicopter contract in 1959, Mr. Malcolm Harned, chief engineer of the company's aircraft division, predicted that to win the army contract, he and the other company engineers would have to design for levels of aerodynamic and structural efficiency never before thought possible for helicopters. "For instance," he commented, "there has been a belief among helicopter people that a helicopter's aerodynamic drag level could never be brought down to that of fixed wing aircraft. We have made just the opposite assumption."

Prepared in the Design Division of the Department of Mechanical Engineering, Stanford University, by Eugene J. Echterling under the direction of K. H. Vesper with support from the National Science Foundation. The cooperation of Mr. Malcolm Harned, Mr. Harvey Hay, and Mr. Herbert Lund of Hughes Tool Company is gratefully acknowledged.

Hughes Tool Company began in 1909 as a manufacturer of oil well drilling equipment. It did not enter helicopter development until shortly after World War II, in contrast to companies such as Sikorsky and Hiller Aircraft which had been involved with helicopters since the late 1930's. One of Hughes' earliest helicopter projects was the XH 17, the first large pressure jet flying crane. With power supplied to the rotor blades by exhaust jets in the blade tips, this ship, flying at a gross weight of 47,500 pounds proved the feasibility of jet power for rotary wing aircraft. An experimental model successfully flew tests from 1952 through 1955.

In 1955, Hughes began a development of a low-cost, light weight, two-place helicopter powered by a reciprocating engine for the United States Army. This ship was evaluated by the Army in 1959 and was considered to be a highly reliable aircraft. However, in 1959, the Army also made the decision to begin eliminating recriprocating engine helicopters from their inventory. They anticipated replacement with higher performance, turbine-powered helicopters. The Army thus decided against the use of Hughes' light-weight two-place helicopter, but the company developed it into a successful commercial version selling for $22,950. Sales of this ship, called the model 269A (Exhibit A-4), grew to approximately one-half of all commercial light helicopter sales in the United States.

Army LOH Program

In 1956, the Army released to the entire aircraft industry a request for proposals for a Light Observation Aircraft (LOA) (not necessarily a helicopter), to replace fixed wing aircraft, the L-19, and two helicopters, the H-13 and H-23 (Exhibits A-1, 2, 3). Brig. Gen. John J. Tolson, Army Aviation Director at the time, explained that the decision was based on Army plans to reduce the types of aircraft in their inventory from seventeen to about six in the near future.

In 1959, after reviewing proposals submitted by the aircraft industry, the Army decided to select a helicopter as the new LOA. The name was changed from an LOA program to an LOH program. The Army also decided to use a 250 HP turbine engine for the LOH instead of a conventional reciprocating engine. This decision was based upon the belief that greater over-all efficiency could be achieved using a light weight gas turbine engine.

Fifteen manufacturers entered proposals in 1961 for what they hoped would solve the Army's need for an LOH. From these fifteen competitors, the Army selected three companies to receive development contracts for the LOH. The companies were Bell Helicopter of Fort Worth, Texas, Hiller Aircraft of Palo Alto, California, and Hughes Tool Company of Culver City, California

The development contract called for the delivery, from each competitor, of five prototype helicopters which were to be evaluated in a six

month test series. The prototypes were to be delivered to the Army at Fort Rucker, Alabama, in October of 1963. The competition was to begin formally in January and end in June 1964. The test plans included about 1700 flight hours of verification of performance, stability and control, logistics requirements, and effectiveness on simulated combat missions. The Army wanted the LOH to perform the functions:

1) visual observation and target acquisition

2) reconnaissance

3) command and control

4) utility tasks at company level while organically integrated with field troops.

Detailed requirements were given in type Specifications TS-153, from which the key items were:

Payload	400 lbs + pilot
Min. cruise velocity	110 knots
Min. endurance	3 hours
Dynamic components Minimum life	1200 hours
Hover ceiling	6000 ft. at 95°F

The Army's <u>Request for Proposal</u> also stated the following qualitative needs:

> Attention is specifically drawn to the paramount desires of the U. S. Army for a small, lightweight, inexpensive, reliable, and easily maintainable vehicle most nearly capable of fulfilling the technical requirements of type Specifications TS-153.

Preliminary Design

Mr. Harned commented on the design philosophy with which Hughes had begun the project: "When we went into this competition, it seemed obvious to me that we would have to come up with a helicopter that was a whole lot better than that of any of our competitors. In comparison with companies like Hiller and Bell, we weren't as deeply entrenched in the helicopter business. Our competitors were established Army suppliers, whereas we were not. Thus, we felt that if our ship was only a little bit better, we would still lose the production contract, with our inexperience given as a cause of failure."

"To achieve the requirements set by the Army, we saw the need for solving several basic, general problems involving:

1) drag level (aerodynamic)

2) weight

3) maintainibility

None of the problems was separate, however. The overall design became an integration of structural, mechanical, and aerodynamic elements with complicated interactions.

An early design consideration was selection of the fuselage configuration. Mr. Harned explained how this proceeded: "We began by asking what the absolute minimum for parasite drag could be on a fuselage -- not necessarily for a helicopter, but for any shape of fuselage. Drag coefficients expressed as a function of fineness ratio can be found in a large number of aerodynamic texts. This is where our fuselage design was started. We did a great deal of complicated analytic design just to determine the minimum drag for the fuselage alone, which we knew we would not achieve in a final completed configuration." As seen in Exhibit A-5, a fineness ratio of approximately 2.5 yields the minimum drag coefficient of 0.05. Thus, Hughes engineers felt the minimum fuselage drag could ideally be achieved with the shape seen in Exhibit A-6. Total aerodynamic drag for an airplane is normally expressed as the number of square feet of a flat plate which, when pushed through the air, would produce the same drag. Helicopter drag coefficients had always before been much higher than those of fixed wing aircraft. For example, the Hughes Model 296A had a drag equal to approximately 13 square feet of frontal area. Mr. Harned commented on this aspect of the LOH, "When we set a drag level of four square feet as our goal for this helicopter, many people thought we were being ridiculous. Many people believed that such a low level was unattainable."

Mr. Lund added, "When considering possible fuselage configurations, a primary constraint is the cross section necessary to accommodate a seated pilot, passenger and controls. Quite naturally, our early thinking centered around the cross-section of the Model 269 (Exhibit A-4) as a starting point, since both are light helicopters. Also, before we started any layout work, we both decided to try using a rotor height the same as in the 269. This height allows head clearance and is also low enough to fit into the cargo department of a C-130 Army transport plane without dismantling. In a small helicopter, the ease of shipment is a big consideration. That is why we have been quite concerned about easily fitting our helicopter in a C-130."

Component Decisions

Another phase of the preliminary design study that proceeded simultaneously with fuselage design was determination of the minimum possible rotor size which would accomplish the mission objectives. Initial studies showed that a rotor diameter of around 25 or 26 feet would fulfill the Army's requirements. The Hughes 269A helicopter has a rotor diameter of 25 feet and uses blades which have been developed into low cost production items. Consequently, the 269A rotor blades were chosen for the LOH. However, because of the higher gross weight for the LOH, four blades are required instead of only three as in the 269A.

An Army objective was the provision of a cargo compartment capable of carrying four fully equipped soldiers. This, with the passenger in the pilot's cabin, provided a five man fire-power team in addition to the pilot. Mr. Lund commented on cargo compartment location, "We felt the location of the cargo compartment directly under the rotor mast was one of the most important early objectives. Such a location allows for indiscriminate loading without fear of dangerously shifting the center of gravity. A ship of this size can only tolerate a center of gravity shift of about four or five inches. This is a stability requirement based upon the fact that, during flight, the ship is suspended beneath the rotor hub. If large variable loads, such as fuel tanks, are located more than a few inches away from the center of gravity, movable ballast must be provided to relocate the center of gravity under different load conditions. Mr. Harned emphasized Mr. Lund's comment, "To provide the Army with the kind of flexibility they were looking for in this aircraft, we wanted to provide a cargo compartment centered directly below the rotor mast with all weight as low in the ship as possible."

Mr. Lund pointed out that, to provide for passenger crash safety, it was desirable to have large, heavy compartments located someplace other than above any possible passenger location. This meant that the 126 pound Allison turbine engine (Exhibit A-7) should be as low in the ship as possible. However, other requirements such as engine air intake and exhaust ducting indicated that a high engine location might be desirable. Mr. Lund commented on this problem, "We wanted the engine air intake ducting to be as direct as possible and the exhaust air duct to be in a safe position so as to prevent overheating of passengers and fuel, and also to eliminate any hazard to ground personnel or vegetation at any possible landing site. The Army had experienced problems with piston-powered aircraft setting dry grass and brush afire on the ground. They could visualize this ship setting down in a dry field of tall grass and immediately starting a blazing fire. As a result, we did a lot of testing to determine the self-ignition temperature of a wide variety of weeds and grasses. We found nothing to substantiate the rather extreme fears expressed by the Army. At the exhaust tip, the gas temperature was only 1000°F, and at three or four feet behind the tip, the temperature was only 300-400°F. Another factor which tends to reduce the fire hazard is the fact that the exhaust air blows any light weight combustible

grass or weeds away from the hottest exhaust area. We felt that the Army was unnecessarily worried about this problem, but we knew that in their evaluation of our designs they would try their very hardest to set a dry field afire with our exhaust gases."

Another factor related to engine location is the cooling of engine oil. Mr. Lund commented on this problem: "Allison sells this engine without cooling oil systems. They tell us to provide a cooling system for the oil. We have tried to get them to provide this, but their feeling is that for each different application of their engine, the users should design a cooling system best suited to his own particular needs. We are merely given the FAA certified oil cooling requirements, which, for this ship, state that we must provide 19 pounds per minute of MIL-L-7808 oil at a temperature between 160° and 200°F to the engine oil inlet when the engine oil outlet temperature is 275°F.

Mr. Harned explained some considerations involved in the selection and location of the tail rotor: "A primary locational requirement is to provide adequate tail rotor clearance with respect to the main rotor and also with respect to the ground. We have looked for one of our existing tail rotor drive systems which might be suitable. The system used in our model 269A has been very successful, and is simple, lightweight, and inexpensive. Also, since this shaft runs directly from a main transmission gear box to the tail rotor, it eliminated the need for any intermediate angle gear box. We have decided to use it for our LOH."

"We have assumed from the start that throughout the entire project a very close watch on weight considerations is vital. Only in this way can we get the type of performance wanted for this ship. Structural functions should be combined whenever possible. Weight savings are doubly significant when it is realized that each added pound of weight requires one to two pounds of additional helicopter to carry it."

Need for Sketches

Before any wind tunnel testing of models could begin, it was necessary to sketch the overall appearance of the ship, a task which Mr. Lund was to perform. These sketches would have to show the arrangement of the main components and of passenger and baggage compartments. Since compromises of desirable features would probably be necessary in integrating the main components, Mr. Lund felt he should generate several alternative sketches, with clear recognition of the advantages and disadvantages of each.

When the sketches were worked out, wind tunnel testing would begin using a 1/6 scale model of the ship to begin optimization of a total aerodynamic drag, including effects of the main rotor system, tail rotor, and boom, and landing gear. Mr. Lund emphasized the importance of giving careful thought to implications of the sketches before the models were built, observing, "The more problems we can resolve before we get into the wind tunnel testing, the more time and money we can save. It is usually much cheaper to catch a bad design feature in the sketching or layout phase than in the later phase of models and mockups."

Exhibit A-1: Miller OH-23G


ARMY

Exhibit A-3: Cessna L-19

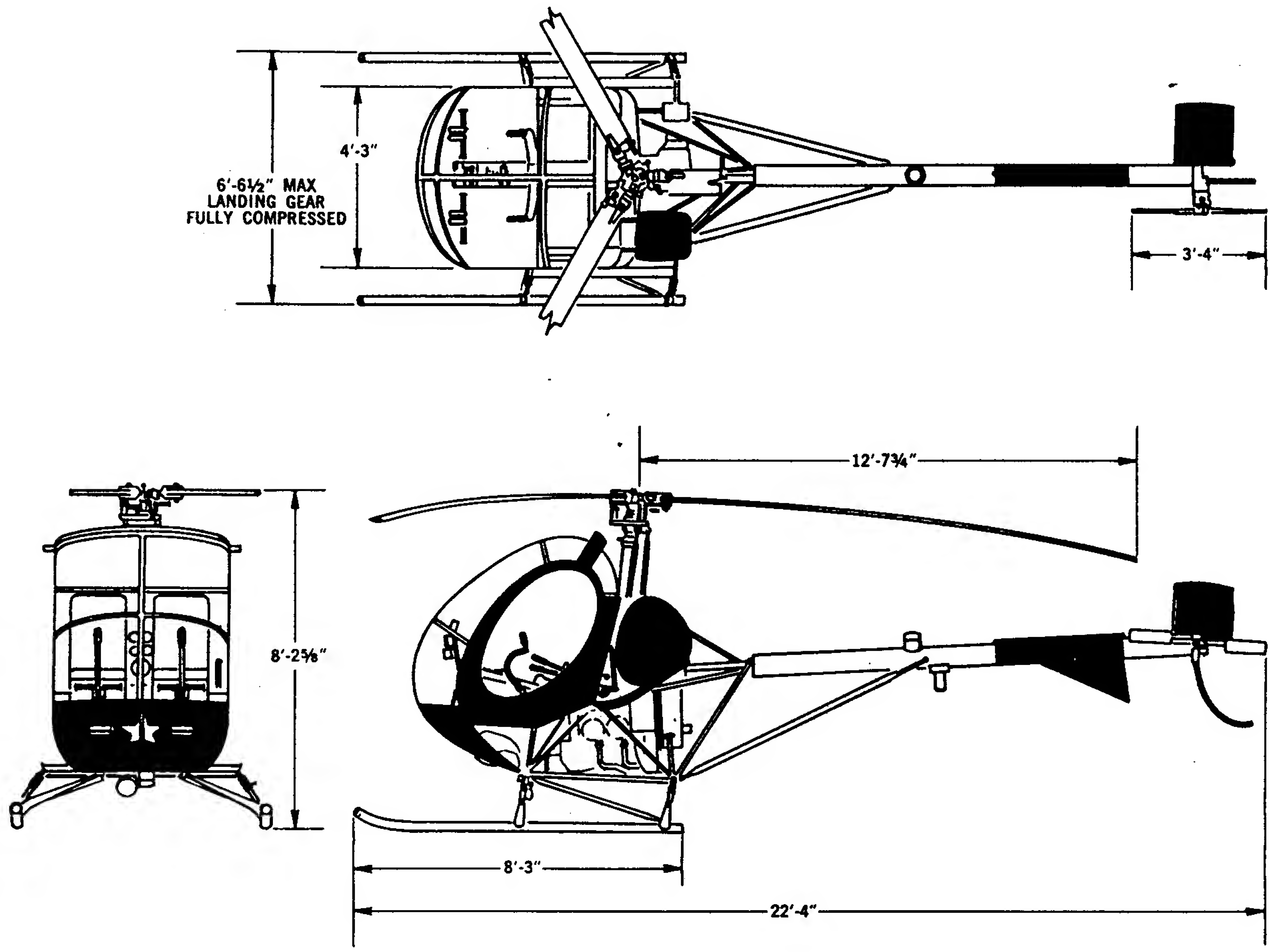


Exhibit A-4: Hughes Model 269A

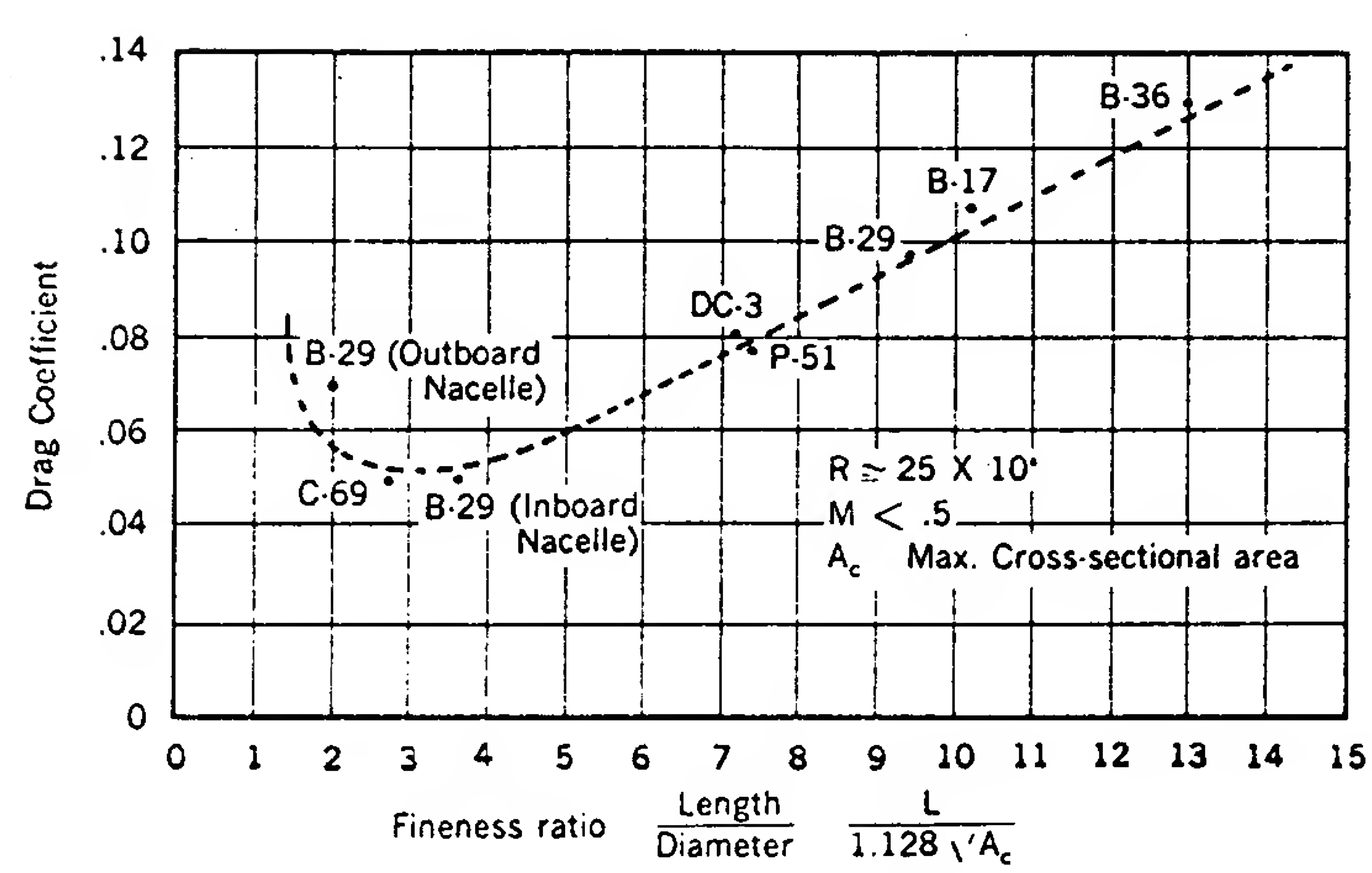


Exhibit A-5: Effect of Fuselage Fineness Ratio upon Drag. (Courtland D. Perkins & Robert E. Hage, Airplane Performance Stability and Control, Wiley & Sons, Inc., 1949)

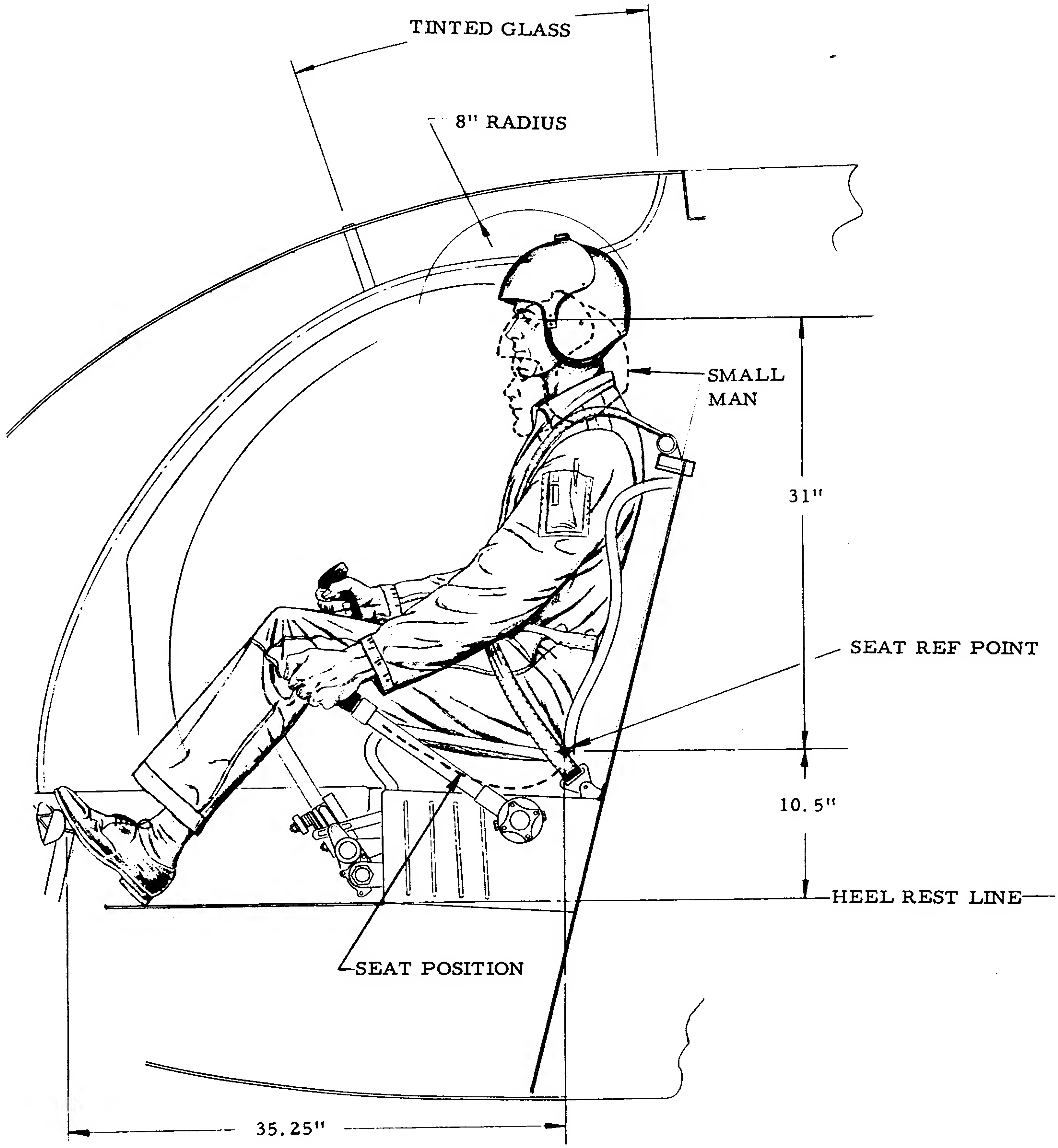
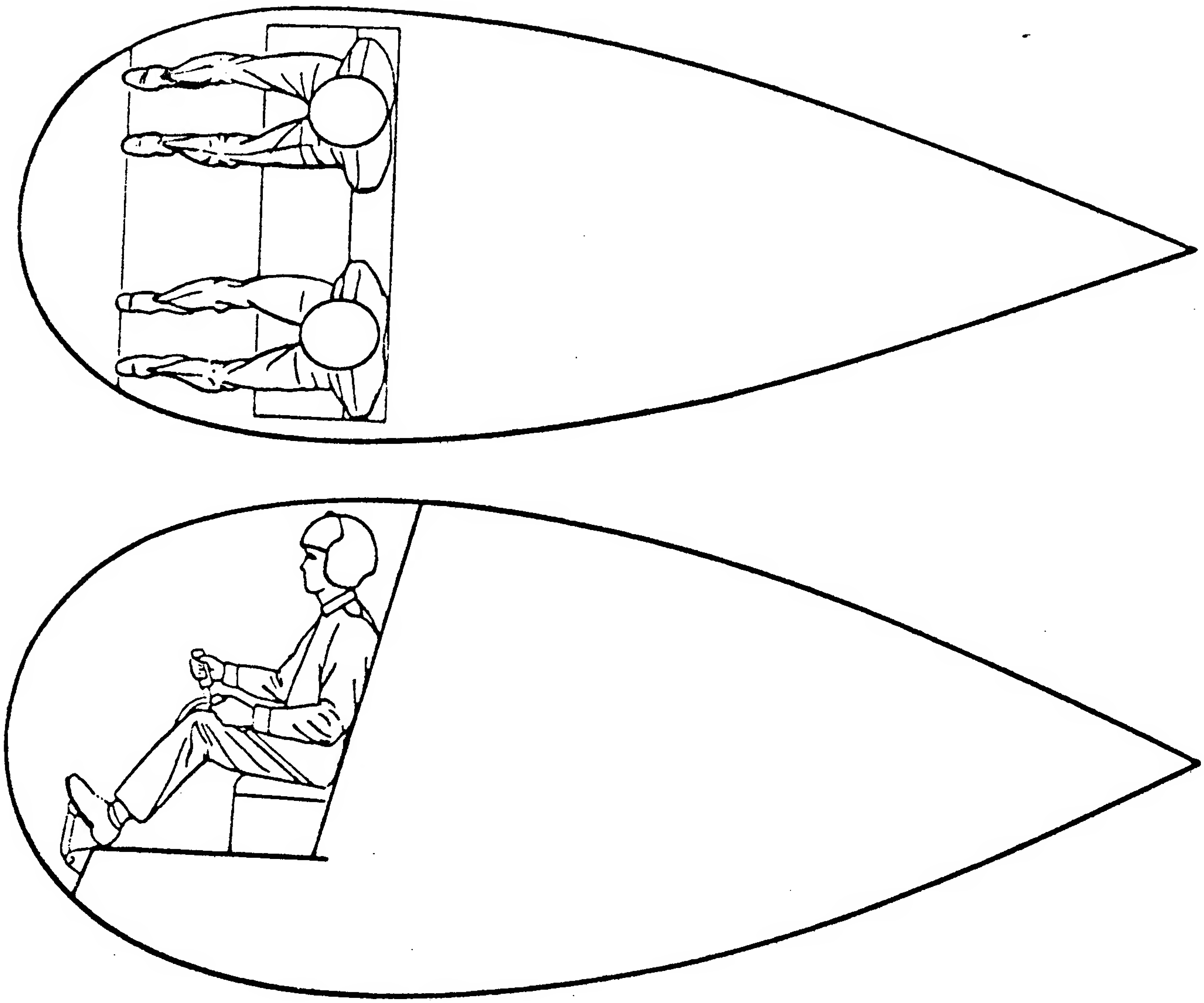


Exhibit A-6 (a): Pilot Position in Cockpit



FINENESS RATIO: Approximately 2.5

Exhibit A-6 (b): Optimum Fuselage Shape for Minimum Drag.

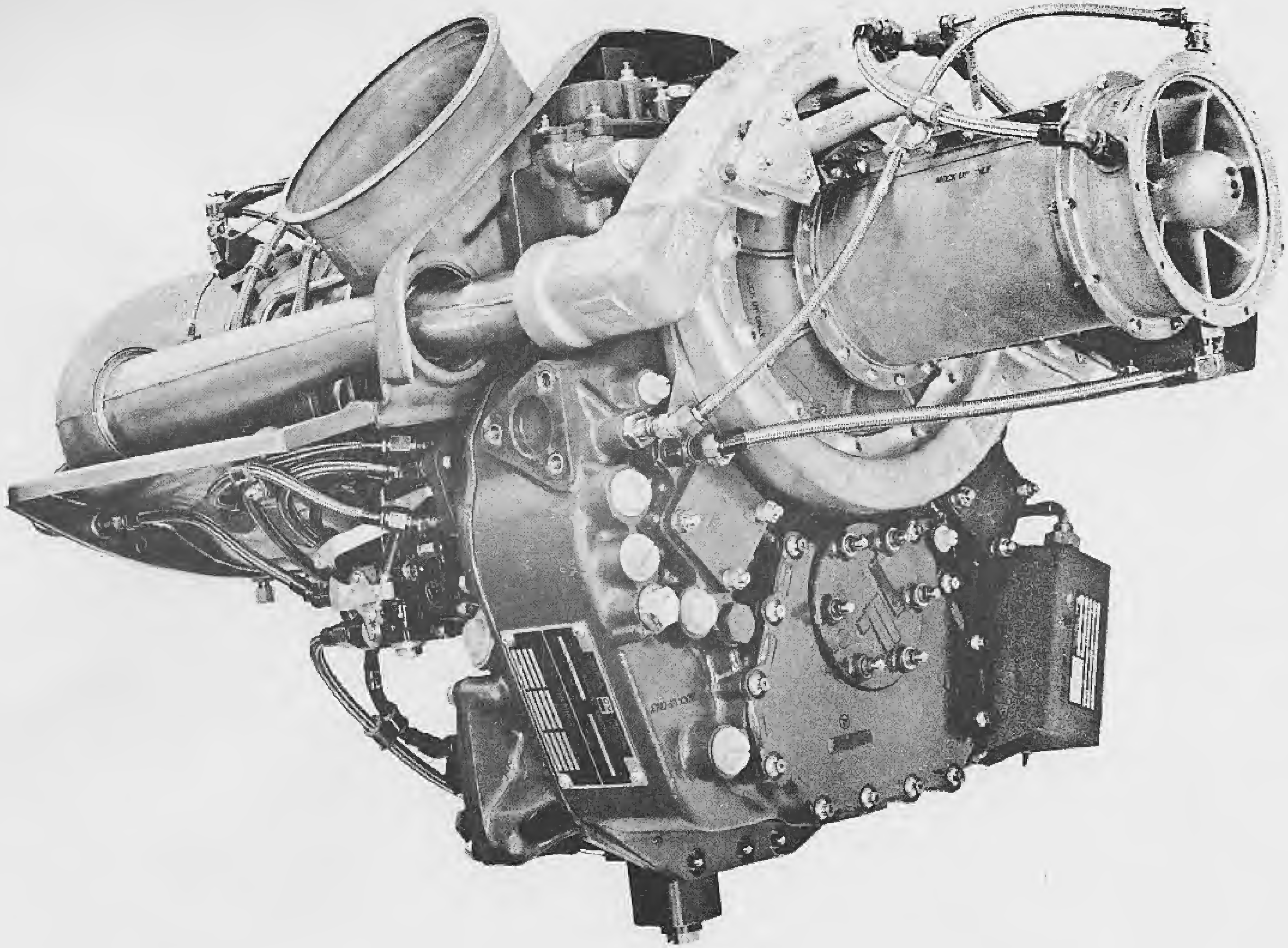


Exhibit A-7: **Allison model T63-A-5 turboshaft engine.**

HUGHES TOOL COMPANY, AIRCRAFT DIVISION (B)

Overall Fuselage Configuration and Engine Cooling Requirements

The final arrangement of components within the chosen fuselage required several months of intensive design activity. All phases of the design were related, with attention to weight reduction being perhaps the most significant consideration common to all phases. Mr. Harned emphasized the fact that no single design detail could be attended to without considering the effect upon such overall considerations as total weight, aerodynamic drag, maintainability, etc. Exhibit B-1 shows the basic configuration, and Exhibit 2 shows those of the competitive design by Hiller.

After selection of the minimum drag profile to accommodate pilot and one passenger seated side by side, Mr. Lund looked for ways to reduce aerodynamic drag further. "We started with a cabin cross section very much like that of our model 269A. To approximate more closely a tear drop shape, we faired the sides into the top and bottom, thereby creating an oval cross section.

"From my very earliest sketches throughout the preliminary design I concentrated on locating the cargo compartment almost directly below the rotor head. In my early sketches I borrowed heavily from the 269A configuration. Some configurations had low engine and transmission, with a long rotor shaft; some had high engine and transmission. A change in one component location usually affected the location of something else."

The final cargo compartment location chosen was directly below the rotor mast, as shown in Exhibit B-3. This location required that the main transmission be located directly above the cargo compartment. The selection of the main transmission involved several complex design considerations including tail rotor drive system, engine location, cooling requirements, and fuselage structure. In addition, lubrication was an extremely important consideration of transmission selection. In attempting to achieve the desired Army objective of low maintenance, Mr. Harned decided at the beginning of the LOH project that no grease fittings were to be used on the ship. It was his feeling that permanently lubricated moving parts would be necessary to provide the low maintenance which the Army desired.

The main gear box itself included only two bevel gear meshes on three shafts (Exhibit B-4), an input shaft turning at 6000 rpm, the tail rotor shaft turning at 2000 rpm, and the main rotor shaft turning at 600 rpm. The input shaft connects directly with the engine, which is mounted as

shown in Exhibit B-5. This engine location represents a compromise involving factors such as crash safety, accessability, engine air ducting, cooling requirements, and fuselage structure.

Based upon the goal of low weight and low maintenance, a direct tail rotor drive such as that used in the model 269A was chosen for the LOH. Coming directly from the main transmission, no intermediate angled gear box was needed between the transmission and the tail rotor gear box. At each end of the hollow aluminum tail rotor drive shaft, flexible couplings were used to eliminate universal joints which would require lubrication.

The basic structure (Exhibit B-1) was the result of an extensive program of structural design and weight analysis. Mr. Harned commented on this, "By paring the weight of a ship down as we did on the LOH, you reduce your tolerance for error dangerously. For this reason we were forced to consider a great many seemingly small details throughout our structural analysis." He explained the efficiency of the basic structural approach adopted for the LOH, "A truss was developed with a deep beam and a torque box forming the foundation. The two sides of the truss picked up the main gear box at the top and supported the concentrated lift load applied there by the rotor. With this basic structural arrangement, all the concentrated loads experienced by the fuselage are applied at the corners of the truss. There is relatively little bending in the structural system, and there are minimum length load paths in all cases. This basic structural arrangement also offers excellent crash protection."

Cooling Requirements

For Federal Aviation Agency certification, a system had to be provided to cool the lubricating oil in the Allison engine. Specifically, as Mr. Lund pointed out earlier, on a 117° F day such a system had to be capable of cooling 19 pounds of type MIL-L-7808 oil per minute from 275° F to between 160° and 200° F. In addition, the FAA required a cooling system to keep the main transmission oil temperature below 240° F.

Mr. Harned commented, "We want an engine oil cooling system with minimal mechanical or hydraulic complexity. Existing helicopters usually have a radiator and a separate shaft for a fan. This requires additional shafting with an associated system of brackets, bearings, and driving gears or belts and pulleys. Such a system adds weight and, as total complexity of the ship increases with addition of such a system, the chances for a component failure increase also."

There were several reasons for providing cooling air flow through the engine compartment. These included:

1) engine cooling
2) engine oil cooling
3) engine compartment cooling (to protect the other compartments)

It was also necessary somehow to cool the main transmission oil. Mr. Harned also commented on these cooling requirements, "For cooling a main gear box, all existing helicopters have a separate radiator with a plumbing system for circulating oil between gear box and radiator. We want to eliminate such a system."

The final structural design played an important part in the solution of the transmission oil cooling problem. Mr. Lund explained, "Most helicopters use the transmission as the supporting member between airframe and rotor head. As a result, such ships actually are suspended from the transmission, which in turn is suspended from the rotor head. This requires that the transmission be capable of withstanding large structural loads in addition to normal shaft loads. Our structural design, partly as a result of our attempts to lighten the normally heavy transmission, permitted the use of a very light weight transmission which does not have to support the airframe. Instead, a bell-shaped rotor mast bolts onto the airframe from above and serves as the lifting structural member. The main transmission bolts to the underside of the upper airframe. The rotor shaft passing into the transmission carries no axial load. Therefore our transmission takes none of the lift. Since our transmission did not have to serve as a structural member, we decided to make it with walls thin enough to serve as efficient heat exchanging surfaces, thereby eliminating the extra radiator and associated plumbing normally used to cool transmission oil. The first rough analyses by our thermodynamics group indicated that our idea was feasible. When we first submitted our LOH proposal to the Army, our drawings showed cooling fins on the transmission housing. However, our early prototype transmissions without fins performed satisfactorily and, as a result, no transmissions with fins were ever made. The transmission was surrounded by an air duct which was to direct cooling air around the transmission.

The cooling air flow was to be separate from the engine intake air for combustion. An early plan for separation of air flow was as shown in Exhibit B-5. The intake air was to be brought in through openings on either side of the tail boom. The air was to enter a plenum chamber which fed into the engine intake. The exact shape of the plenum chamber was to depend upon the type of blower system used for cooling.

At this stage of the design, the pattern of cooling air flow around the transmission, into and through the engine compartment as shown in Exhibit B-4 had been generally accepted by the engineers on the project. Estimates of heat rejection rates were in the range of 10,000 (BTU/hr) for the transmission and 54,000 BTU/hr for the engine oil. The heat exchanger selected for cooling the engine oil was located in the engine compartment as shown in Exhibit B-6.

Mr. McJones, a consulting engineer who was involved in cooling system design attempts explained some of the complications, "Because of hot spots which occurred on the engine when no cooling air was passed over the engine, the engine manufacturer told us that we would have to provide cooling air around the engine. We could use the air coming from the engine oil heat exchanger if this air were not hotter than 200° F."

Mr. Lund, LOH project engineer, commented on some of the limitations on cooling system design, "We had to be extremely careful in this design detail, as in all others, to keep the device light weight and simple. Mr. Harned was constantly questioning suggested designs in attempting to eliminate unnecessary weight or complexity. He had a very limited choice of driving systems available, but he did not want us to add any extra shafting with its associated bearings, brackets, and drive system if we could possibly avoid it. A profile drawing through the center of the ship (Exhibit B-7) shows the volume we had to work with and also the available shafts for power. One was the engine output shaft operating at a nearly constant 6000 rpm; the other was the tail rotor shaft at about 2000 rpm."

Mr. Lund explained how the engine cooling system evolved, "We first established what volume of air flow we would need for our cooling requirements. Preliminary calculations, based on estimated heat rejection rates, showed that about 675 cu. ft/min. would be needed and a pressure rise of about 50 lbs./ft^2.

"We wanted a blower which required as little hardware as possible. We didn't want to have to add a lot of additional components for a blower drive system. The engine drive shaft, turning at 6000 rpm provided a handy power source to drive a fan, but to get higher rpm, we would have had to add some sort of gearing and separate shafting for fan mounting."

Mr. Harned explained that there were several opinions as to the type of fan which was needed for cooling: "The aerodynamicist who was primarily involved with fan selection kept wanting to use a higher speed fan, which, of course, was always more complex than a fan assembly mounted directly on the drive shaft. The aerodynamicist and I continued to differ in opinion until I finally made the decision to mount our fan directly on the 6000 rpm drive shaft."

One of the Hughes consultants concluded that the cooling requirements of the powerplant system were comparable with the engine of a Volkswagen. A VW engine fan was tested and gave the performance curves of pressure rise vs. flow shown in Exhibit B-8. A drawing of the fan appears in Exhibit B-9. This design was found to meet both the cruise and hover cooling requirements. The efficiency of about 60% was lower than a well designed new fan might offer, but since the total power shorted was only 2 HP this design was acceptable. The weight, however, had to be reduced, and thus a lightweight aluminum fan was designed.

Completed LOH Design

In April 1964, the Army eliminated Bell from the competition. Hiller and Hughes were then asked to submit price quotations in sealed bids, which would be used in determining the final winner of the competition. In May 1965, the Army announced that Hughes was the winner of the production contract. (Exhibit B-10; AWST, June 28, reprint).

The Hughes bid for the helicopter without engine and avionics (Exhibit B-11) was $19,860 for an airframe weighing 830 pounds, or $23.93 per pound. Hiller's bid, without engine and avionics, was $29,415 for 1,200 pounds, or $24.51 per pound. These bids show that the cost of the helicopter is essentially proportional to weight.

Throughout Hughes' development of the LOH, Mr. Harned's philosophy of light weight and maximum simplicity established at the beginning of the project resulted in design innovations. The transmission oil cooling system and the engine cooling fan are two examples of their design approach. Another example is design of the rotor blade retention system. Previous rotor blades had been attached to their rotor mast by means of shafts and bearings (Exhibit B-12). These were necessary to provide three degrees of freedom, for:

1) flapping

2) feathering

3) lead-lag

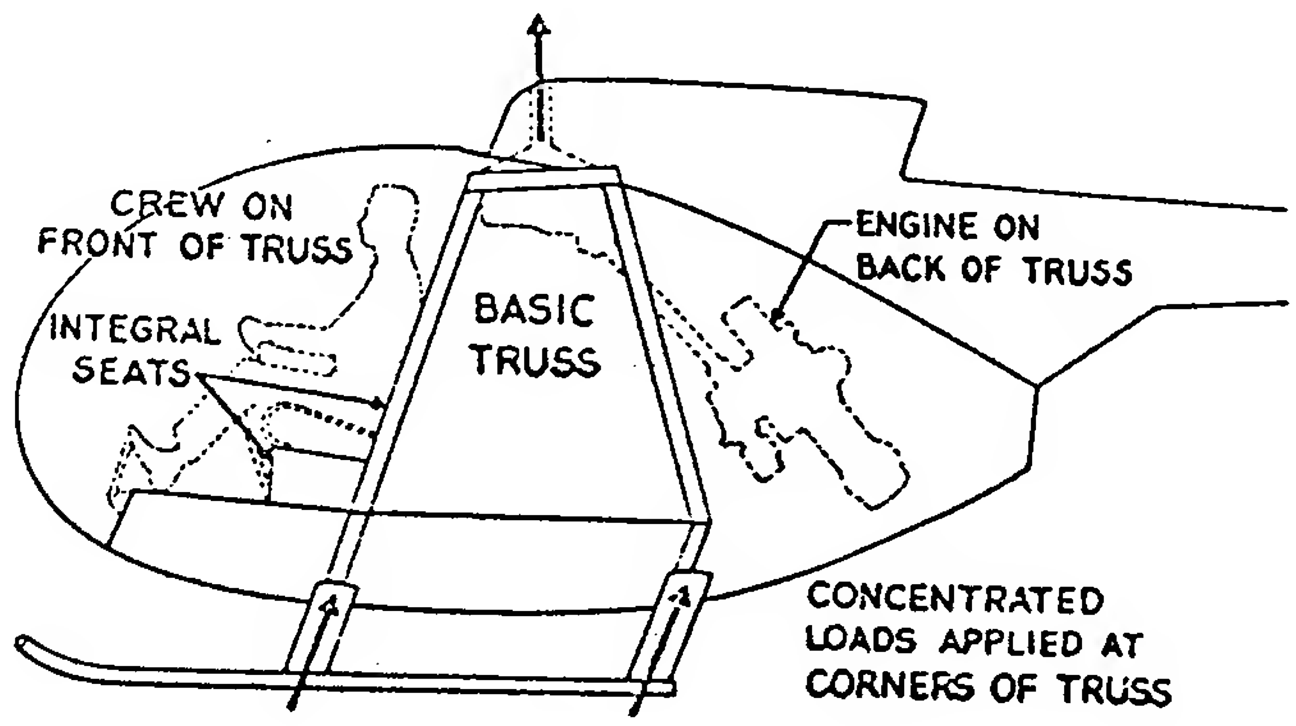
Eight ball bearings are normally used to provide these motions. As a result of designing a blade root which must accommodate this many bearings, unusual loading conditions usually arise through the many components of the hub assembly which must transmit the forces in the rotating blades. There are also lubrication problems associated with the bearings in such a system.

As a result of Mr. Harned's insistence upon reducing the maintenance requirements, a strap retention system (Exhibit B-13) was developed for attaching the blades to the rotor mast. Mr. Harvey Nay, who served as director of engineering on the project, explained how this development proceeded, "Strap retention systems had been attempted before, but none had proven entirely acceptable. When Mr. Harned made the decision to develop a strap retention system for the LOH, there was much popular sentiment for the simultaneous development of a conventional rotor system in the event the strap method failed.

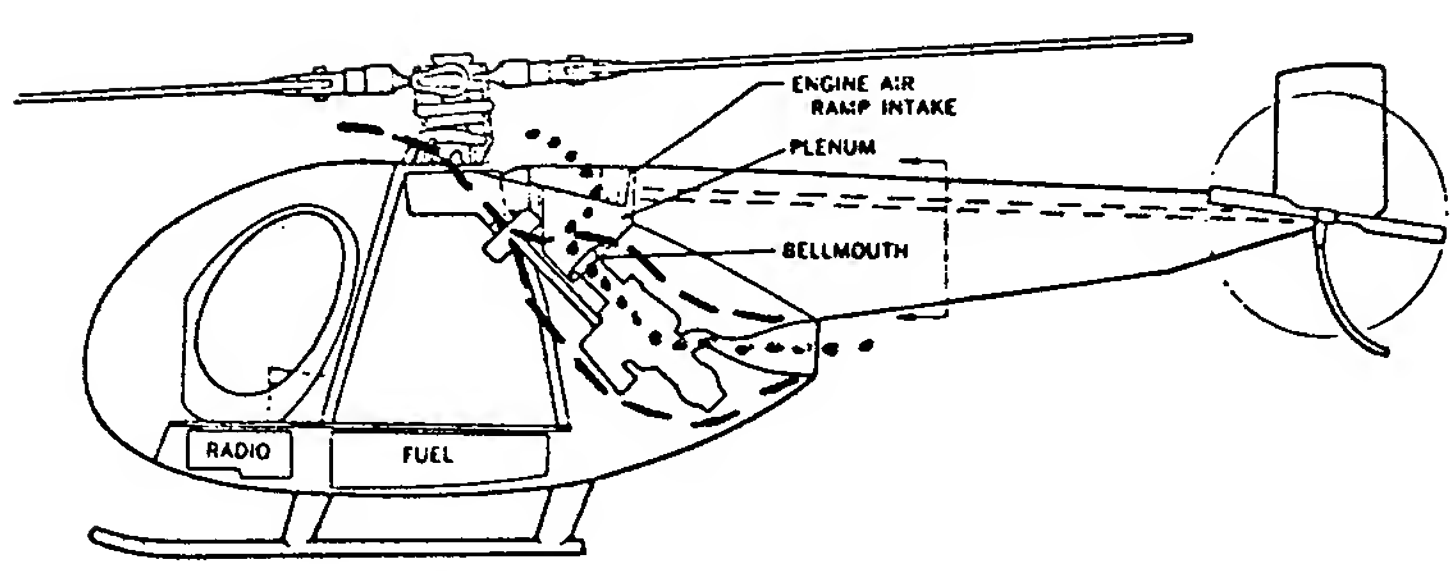
"The total time involved in developing an acceptable strap retention system was about nine months. Although we prefer not to disclose the details of how this developed, let me say that it involved some of the most difficult design problems associated with this project. The design of machines for testing the straps was exceptionally difficult."

The final strap system consists of two strap packs. A rotor blade is supported at each end of each strap. Each strap pack contains 15 high-strength stainless steel straps, .020" thick, six of which can be broken with the remaining nine holding the blade satisfactorily. By providing a continuous load path from one rotor blade root across the hub to the other blade root, this strap retention system saves the large amount of weight usually necessary in rotor hub components which can transfer

blade loads across the rotor hub while still allowing the necessary blade motions. The flap packs flex to provide the necessary flapping motion and twist to provide feathering motion. Lead-lag motion is provided by teflon bearings at the ends of the straps. As a result of this design innovation, lubrication requirements have been totally eliminated from the entire blade retention system. Mr. Harned commented on this development, "The straight line trend of weight (Exhibit B-14) plotted here provides an excellent correlation of a large amount of helicopter experience and you can see that our LOH system falls 35 pounds below the correlation. Such weight savings are doubly significant because each pound of added empty weight requires one to two pounds of additional helicopter to carry it. This weight multiplication factor means that the weight saving in this strap retention system alone probably made our LOH 100 pounds lighter than a conventional helicopter. When this factor is added to the many other weight reductions, it becomes readily apparent why our ship can be both rugged and light in weight at the same time."



Basic Structural Concept.



--------- AIR FOR COOLING

••••••••• AIR FOR COMBUSTION

Air Flow Separation.

Exhibit B-2 Competitive Design By Hiller Aircraft
(From Aviation Week and Space Technology)

FAIRCHILD HILLER FH-1100 helicopter appears larger in photographs than it actually is, but will seat four persons easily. Utility version will have seats for five. First civil model, modified from above configuration, will be flown later this year.

FH-1100 Specifications and Performance

The following specifications and performance data deal with the civil version of the Hiller FH-1100 helicopter and are not necessarily compatible with the OH-5A military version.

Length, rotor turning	41.3 ft.
Length, rotor folded	29.8 ft.
Rotor diameter	35.4 ft.
Tail rotor diameter	6.0 ft.
Stabilizer span	4.3 ft.
Height to top of rotor mast	9.4 ft.
Empty weight	1,395 lb.
Maximum gross weight	2,750 lb.
Overload gross weight (operated under FAR Part 133)	3,000 lb.
Maximum speed, sea level, standard day	110 kt.
Cruise speed, 5,000 ft.	110 kt.
Maximum range/endurance, 5,000 ft., no reserves	410 mi./4.5 hr.
Maximum rate of climb, military gross weight, normal power	1,690 fpm.
Maximum vertical rate of climb, military gross weight	1,020 fpm.
Service ceiling	16,400 ft.
Hovering ceiling, in ground effect	15,950 ft.
out of ground effect	11,100 ft.

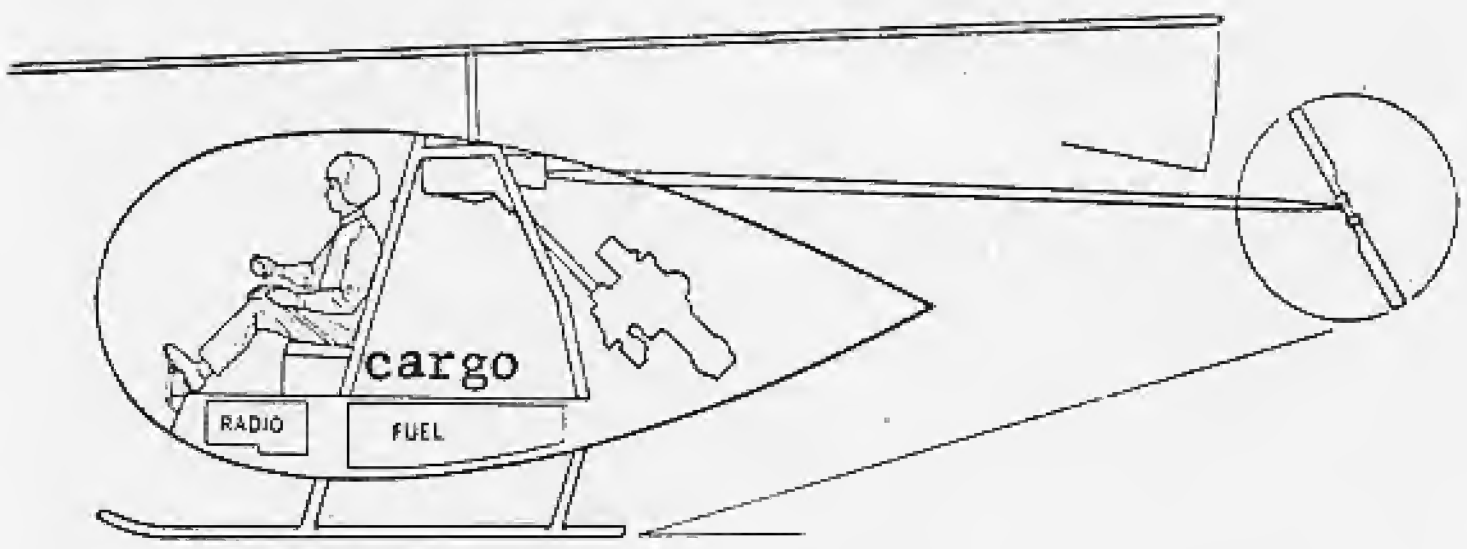


Exhibit b-3 Location of Cargo Compartment Below Rotor Mast and Transmission.

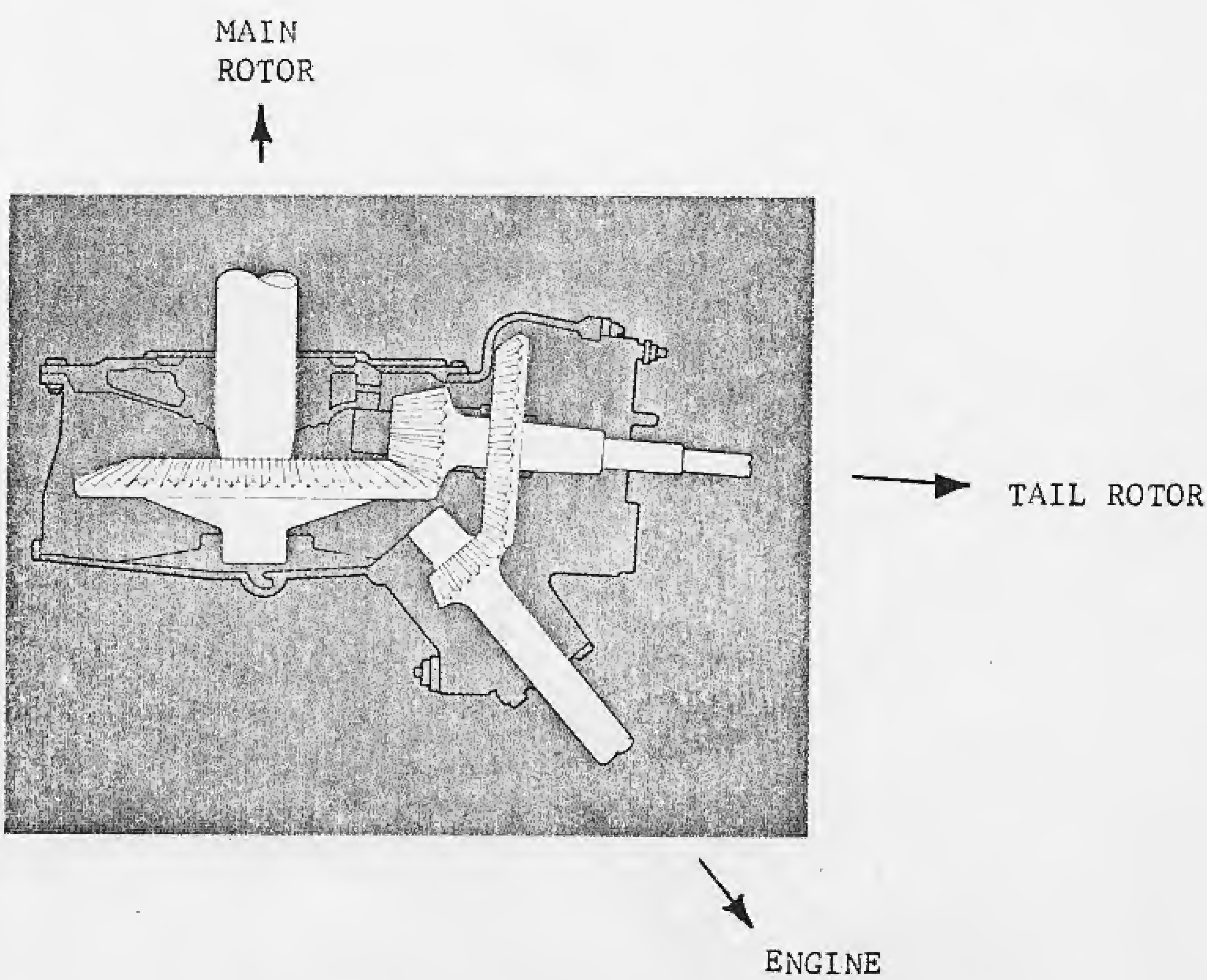
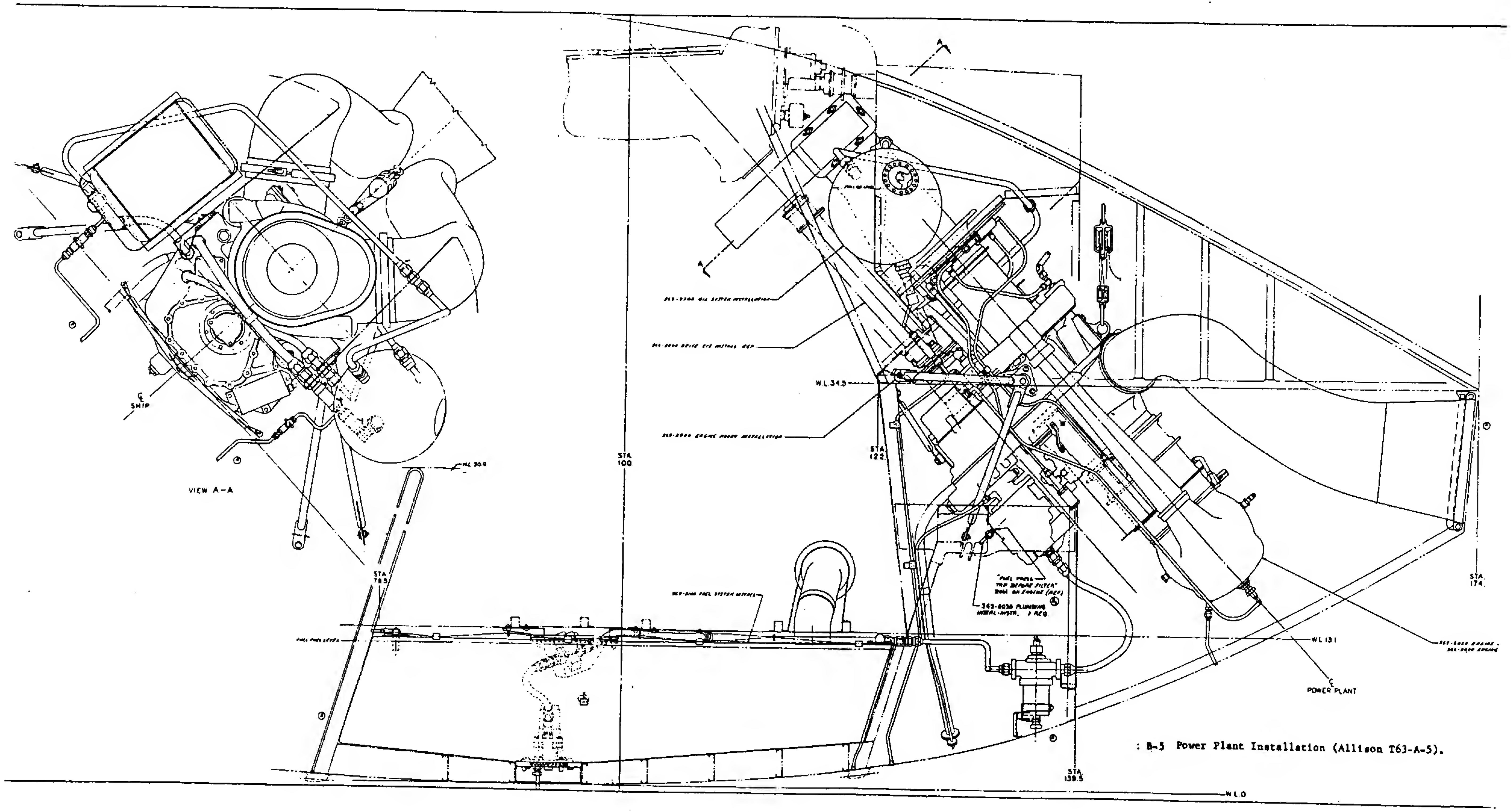


Exhibit B-4 Main Gear Box.



: B-5 Power Plant Installation (Allison T63-A-5).

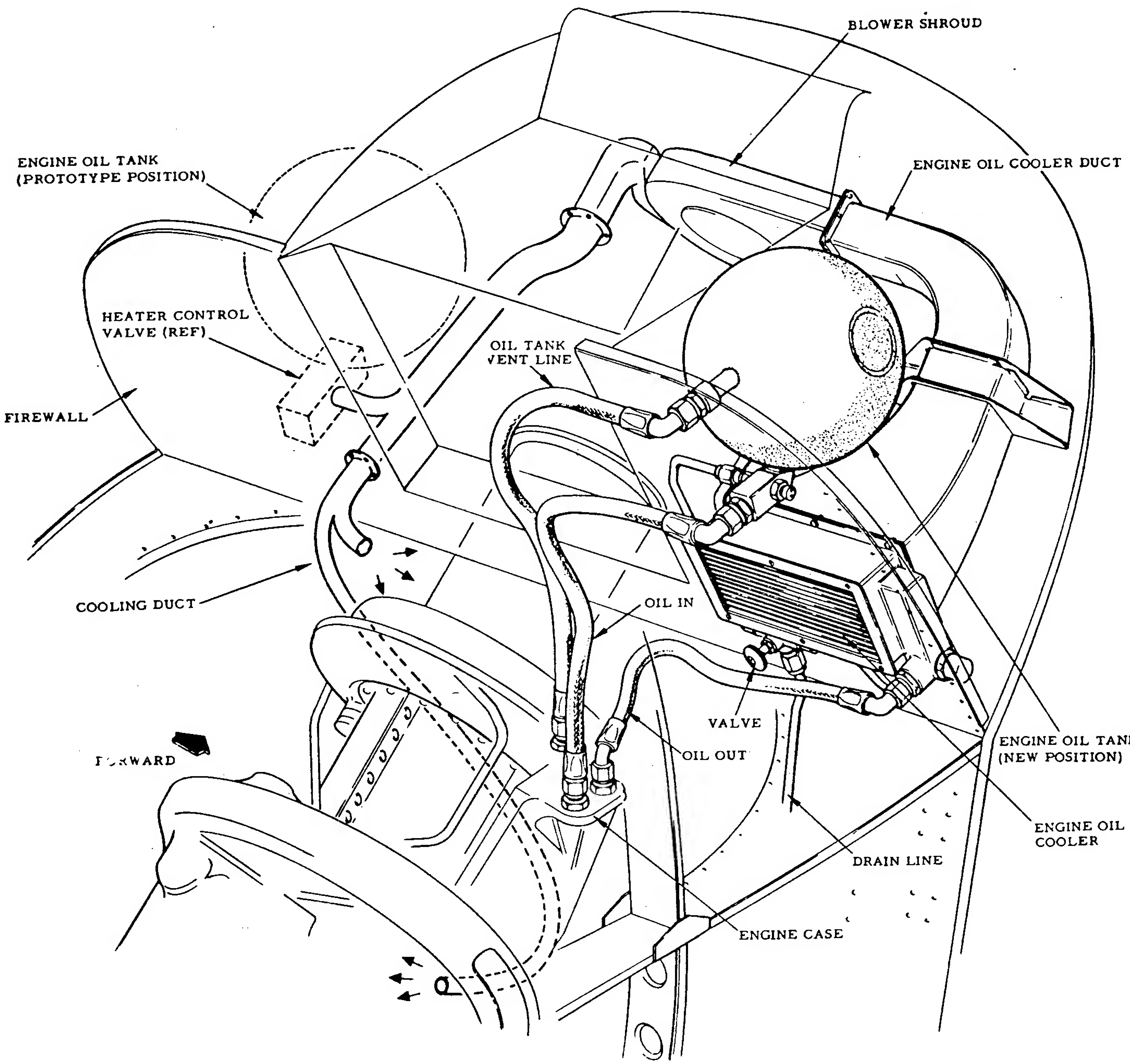
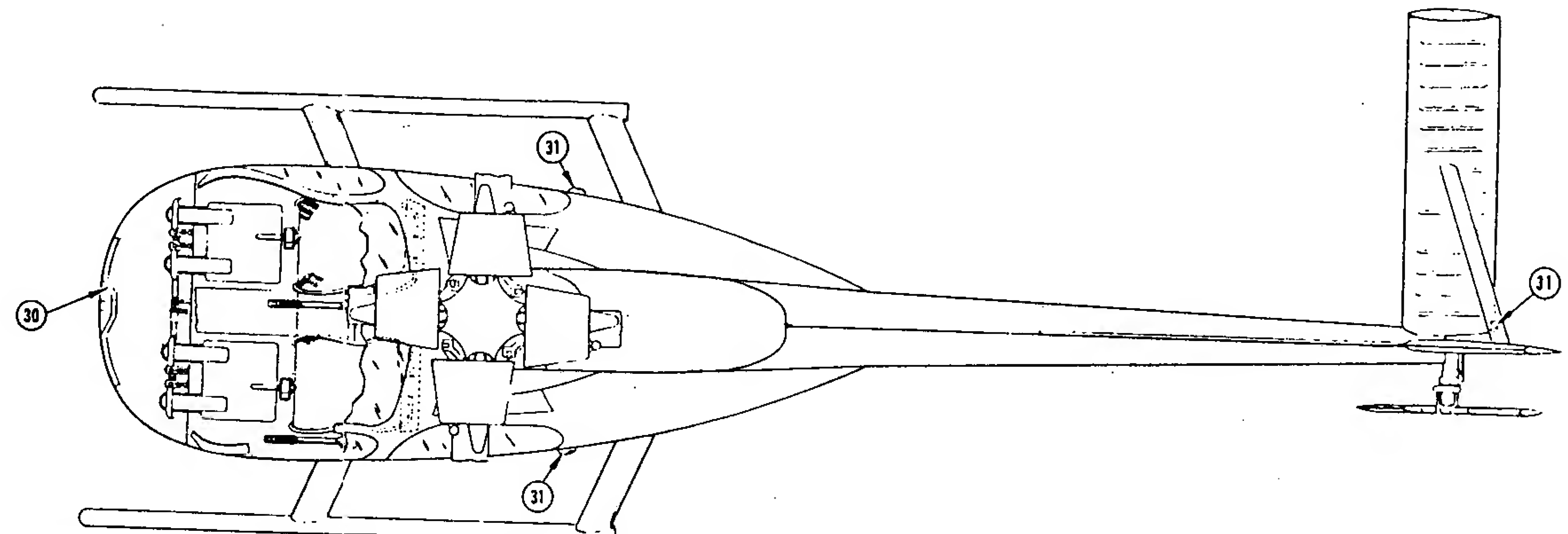
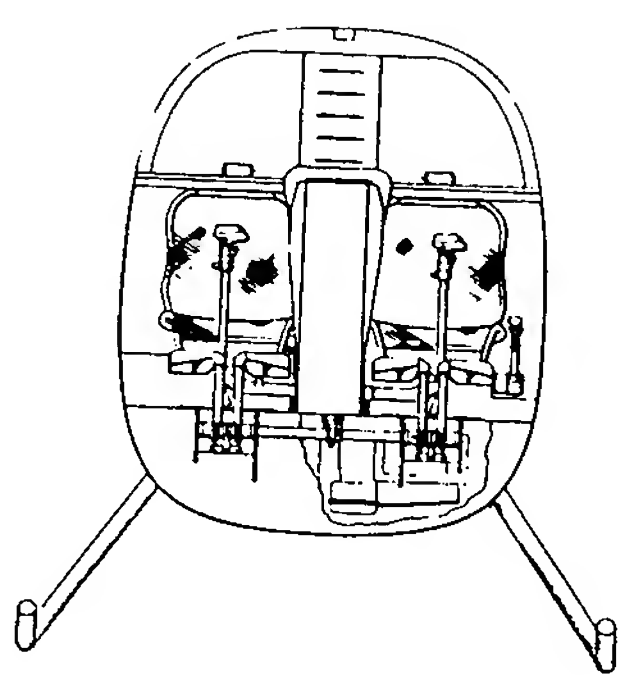


Exhibit B-6:
Engine Oil System Location

1 BLOWER-GEARBOX AND OIL COOLER
2 ANTICOLLISION LIGHT
3 ENGINE DRIVE SHAFT
4 OIL RESERVOIR
5 BLADE
6 ADF SENSE ANTENNA
7 HORIZONTAL STABILIZER
8 UPPER VERTICAL STABILIZER
9 REAR ROTOR GEARBOX
10 LOWER VERTICAL STABILIZER
11 TAIL ROTOR
12 TAILBOOM
13 TAIL ROTOR DRIVE SHAFT
14 DAMPER-TAIL ROTOR SHAFT
15 ENGINE EXHAUST
16 POWERPLANT INSTALLATION
17 LANDING GEAR ASSEMBLY
18 FUEL CELL
19 AVIONICS COMPARTMENT
20 ANTICOLLISION LIGHT
21 RUDDER PEDAL
22 COOLING DUCT
23 COLLECTIVE PITCH CONTROL STICK
24 INSTRUMENT PANEL
25 FLIGHT CONTROL SYSTEM
26 VENTS
27 MAIN GEARBOX
28 MIXER-FLIGHT CONTROLS
29 MAIN ROTOR ASSEMBLY
30 FM HOMING LOOP AND FM/VHF WHIP ANTENNAS
31 NAVIGATION LIGHTS





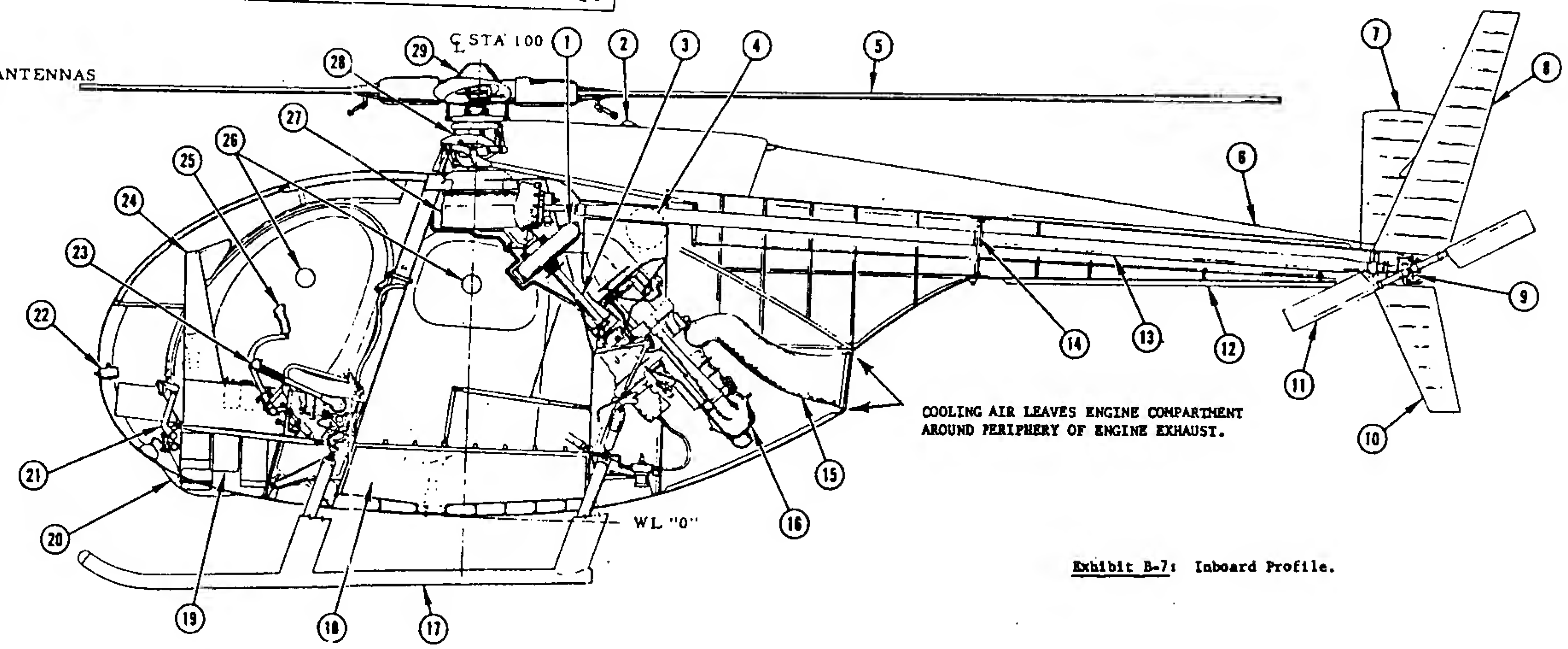


Exhibit B-7: Inboard Profile.

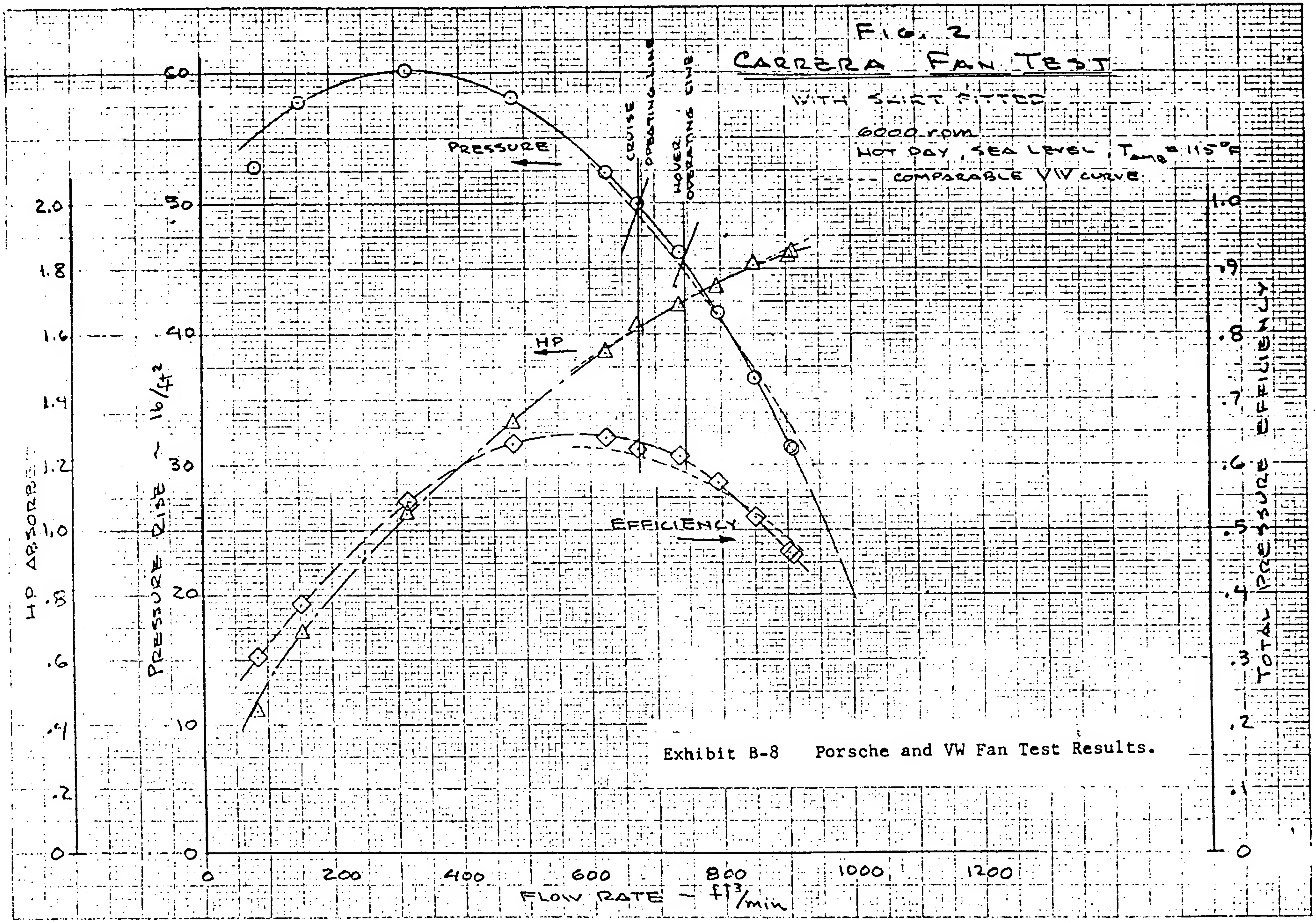
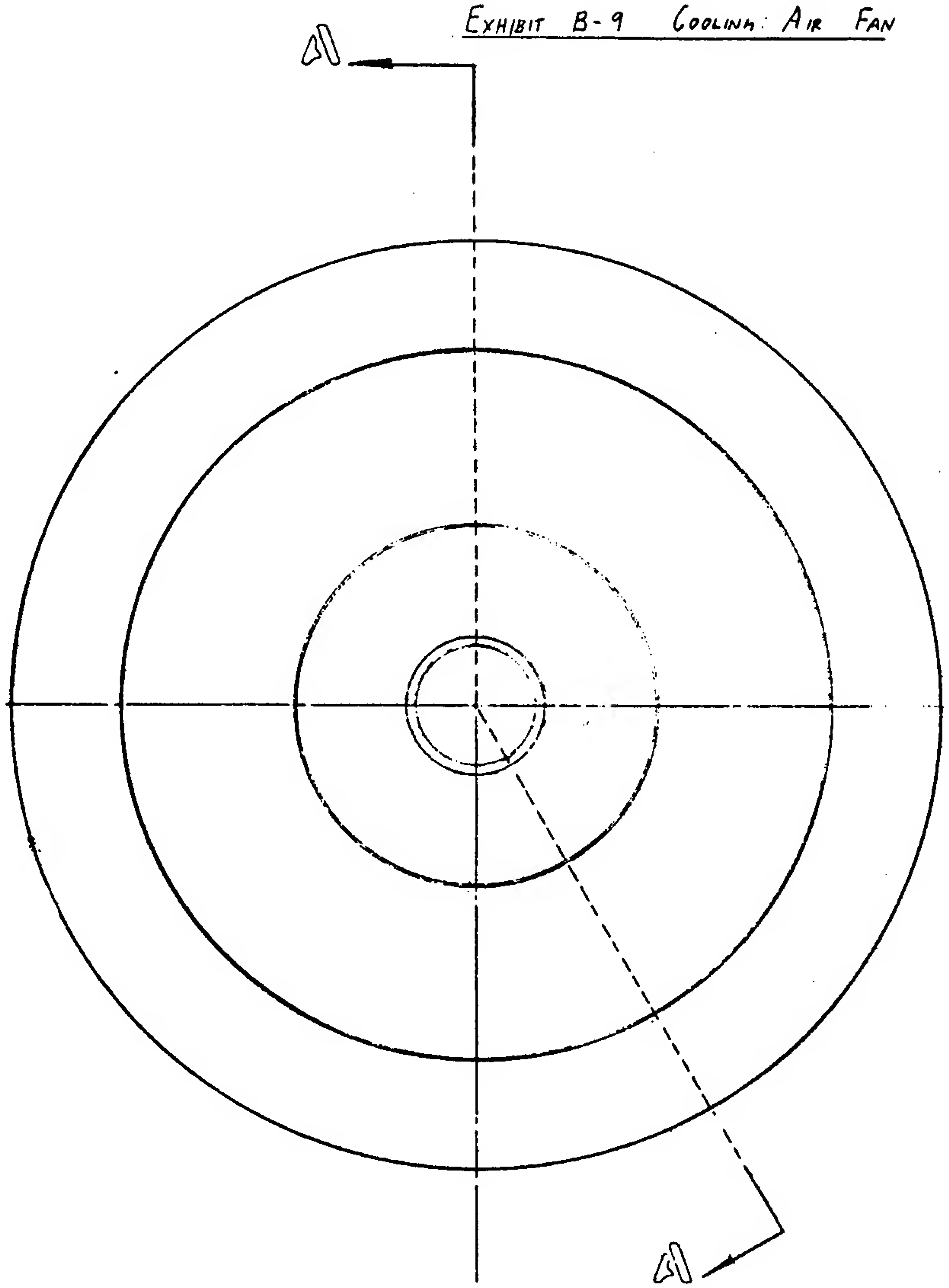
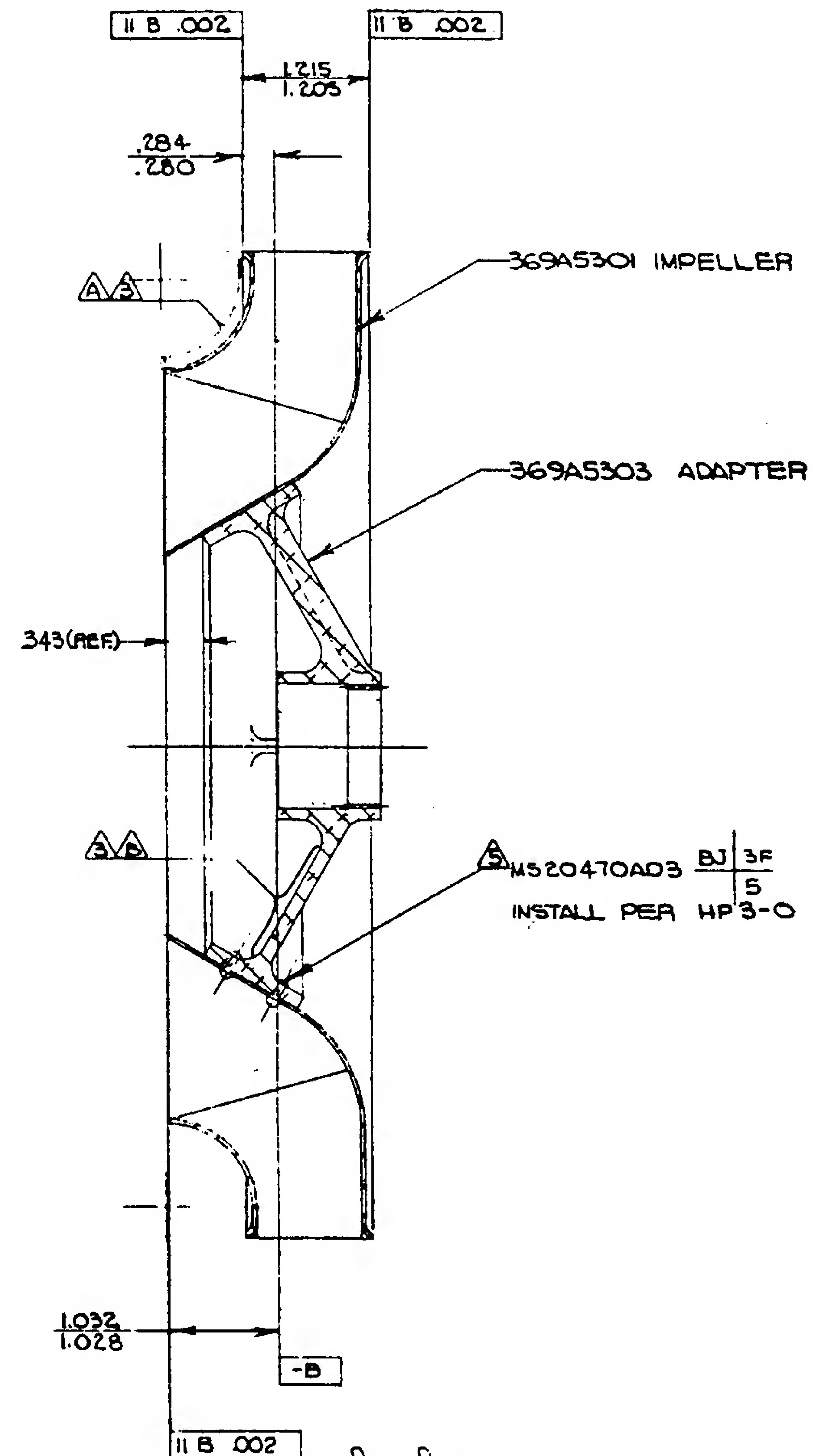


Exhibit B-8 Porsche and VW Fan Test Results.

EXHIBIT B-9 COOLING AIR FAN





SECTION A A

Exhibit B-10 Pg. 1

Hughes Readies OH-6A Facilities; Sales Seen

By C. M. Plattner

Culver City, Calif.—Hughes Tool Co. Aircraft Div. is preparing its facilities here to produce Army OH-6A light observation helicopters (LOH) and the civilian version of the aircraft, the Model 500.

Design and fabrication of tooling is well under way, and Hughes is negotiating with vendors. The company will manufacture the airframe and rotor blades here but expects to buy about half of the OH-6A on a dollar basis, including castings, components and gear boxes from vendors.

The first scheduled OH-6A production delivery date is June, 1966. The first Model 500 is expected to come off the line at about the same time.

7,000 Orders Seen

The company forecasts orders over the next 10 years for up to 7,000 aircraft from the Army and other U. S. military services and envisions a commercial and foreign military market for an additional several thousand aircraft.

This would result in one of the largest helicopter production efforts ever undertaken. Planned production rate at the end of the three-year contract for production of 714 OH-6As is 50 a month. This peak production rate would be achieved by the time the last of the 714 aircraft are delivered in mid-1969 and does not include commercial production.

Hughes, in late May, won the Army's LOH competition with a bid $9,555 lower than Hiller Aircraft's (AW&ST May 31, p. 20) in a two-step runoff ending in a formal price quotation. The runoff was initiated after an exhaustive evaluation which resulted in a virtual tie between the two companies last fall.

A third finalist, the Bell OH-4A, heaviest and slowest of the three aircraft, was eliminated at that time. After dropping the OH-4A, the Army decided to negotiate engineering changes it felt necessary as a result of testing and follow this with a price quotation. In the technical proposals submitted previously, only unofficial estimates of production costs were included.

The real prize in the LOH program has been the advantage afforded the winner in producing a commercial version of the aircraft. This includes production tooling, further refinements negotiated with Army and the psychological sales advantage of claiming to have won the competition.

Hughes announced its plans Apr. 21 (AW&ST Apr. 26, p. 33) to produce two commercial LOH versions, the Model 500 five-passenger executive aircraft and an austere Model 500U utility version. The utility model is capable of carrying seven people with four people seated on the floor in the rear compartment.

Price of the Model 500 is $69,500 while the Model 500U will sell for $65,000. These flyaway factory prices include standard interiors and instruments but not avionics.

Hiller said earlier it would build the FH-1100 (AW&ST Feb. 15, p. 21), a commercial version of its LOH, for $85,000—this includes hydraulically boosted controls but not a stability augmentation system. Hiller's bid to the Army of $29,415 included boosted controls and a stability augmentation system. These additional features and a 400-lb. weight difference make the Hughes and Hiller bids almost comparable on the basis of cost to the manufacturer.

Hughes officials said the company definitely expects to make a good profit from commercial and military sales of the OH-6A but will not break down the profit potential from military and civilian sales separately. Officials say the breakeven point will be reached within a four-year period.

Current projected Army requirement for OH-6As is just under 3,500 aircraft. The helicopter will replace two types of helicopters and one airplane now in the Army inventory—the Bell OH-13, Hiller OH-23 and Cessna O-1.

The three-year Army/Hughes contract for 714 OH-6As has an option provision permitting purchase of 50% more of each year's buy for a total of 357 additional OH-6As. Both Army and Hughes officials are optimistic that the majority of these options will be exercised.

Navy Interested

The Army is the procurement agency for the optional LOHs, but most of these aircraft probably will go to other U. S. military services. The unit price of $19,860 applies to optional aircraft as well as future contracts.

The Navy has evaluated the OH-6A and expressed some interest in it as a turbine-powered trainer. Between 80-100 aircraft would be needed for this purpose. Although the Marine Corps is felt to be a logical OH-6A customer, no official interest has been shown so far.

Malcom S. Harned, vice president of engineering and key figure in design and development of the OH-6A (AW&ST Feb. 3, 1964, p. 72), feels there is

ARMY OH-6A (left) carries M-60 7.62-mm. machine guns. Version at right is hovered by AW&ST's C. M. Plattner.

Exhibit B-10 Pg.2

Topping 7,000

an ultimate potential Navy, Marine Corps and Air Force market for about 1,000 aircraft. Harned feels the Air Force will find many uses for the aircraft such as for personnel transport or missile base air taxi service, but no USAF plans to buy the aircraft have been indicated. Defense Dept. doctrine urging widespread use of newly developed aircraft among all military services is expected to aid sales considerably.

Outside of the U. S. military market, Harned reports strong interest from many potential foreign military buyers and forecasts sales as high as 200 aircraft a year in this field.

Harned also believes the OH-6A will prove so popular with the Army that new uses will be found for it and this buy ultimately will be increased well above the planned 3,500 figure.

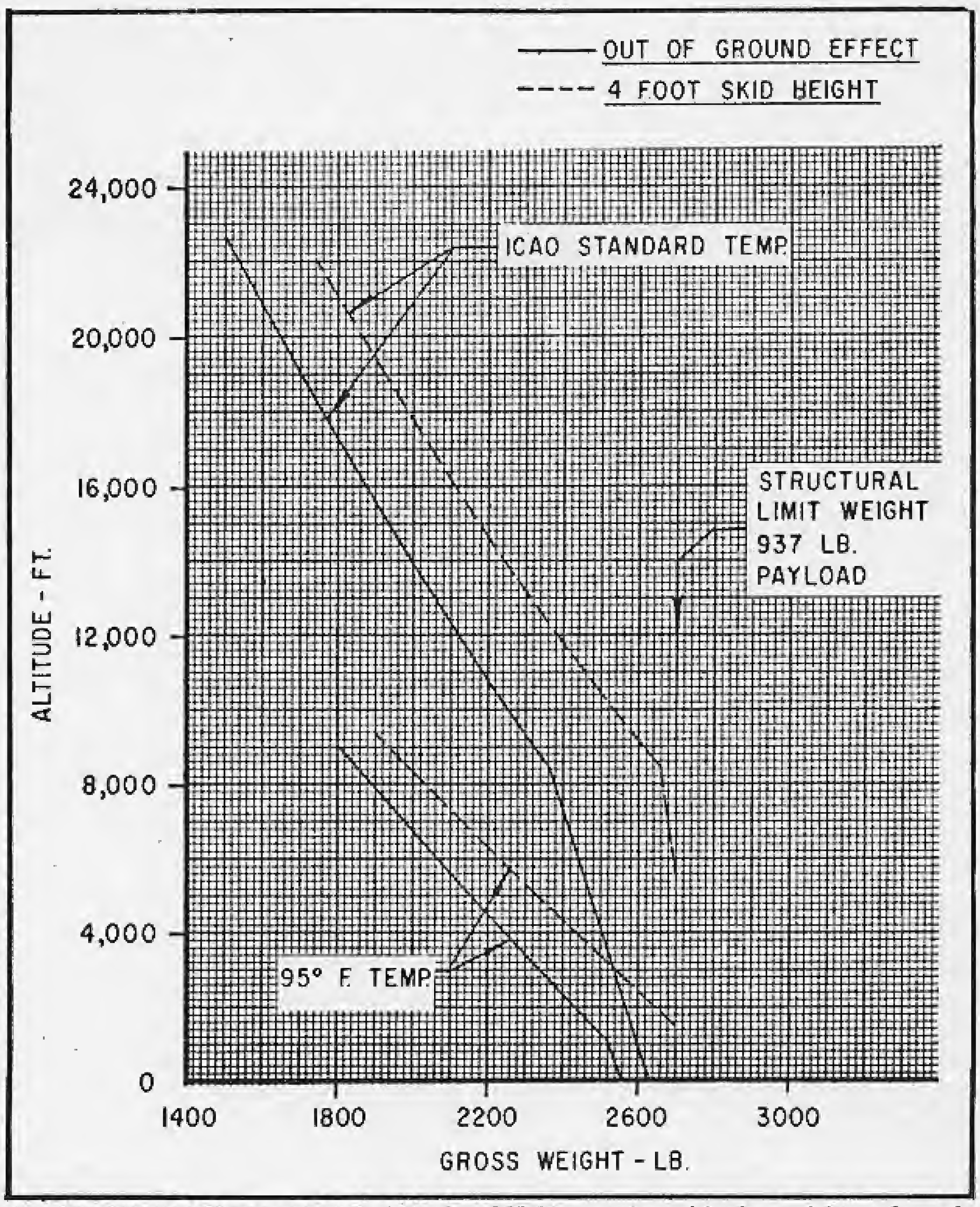
On the commercial sales side, Hughes' primary goal is to sell the Model 500 as an executive transport. Harned noted that last year 1,400 light-twin aircraft in the \$50,000-\$70,000 price class were sold. The company hopes to gain a toehold in this field and is emphasizing the 150-mph. cruise speed and the time saved by landing and taking off at plant sites, eliminating the drive to and from airports.

The 500U utility helicopter will be a stripped version of the Model 500 for use in the field. It will be unpainted and will have no carpeting or upholstery. Harned predicts a market on the order of 200-300 aircraft a year for the Model 500U

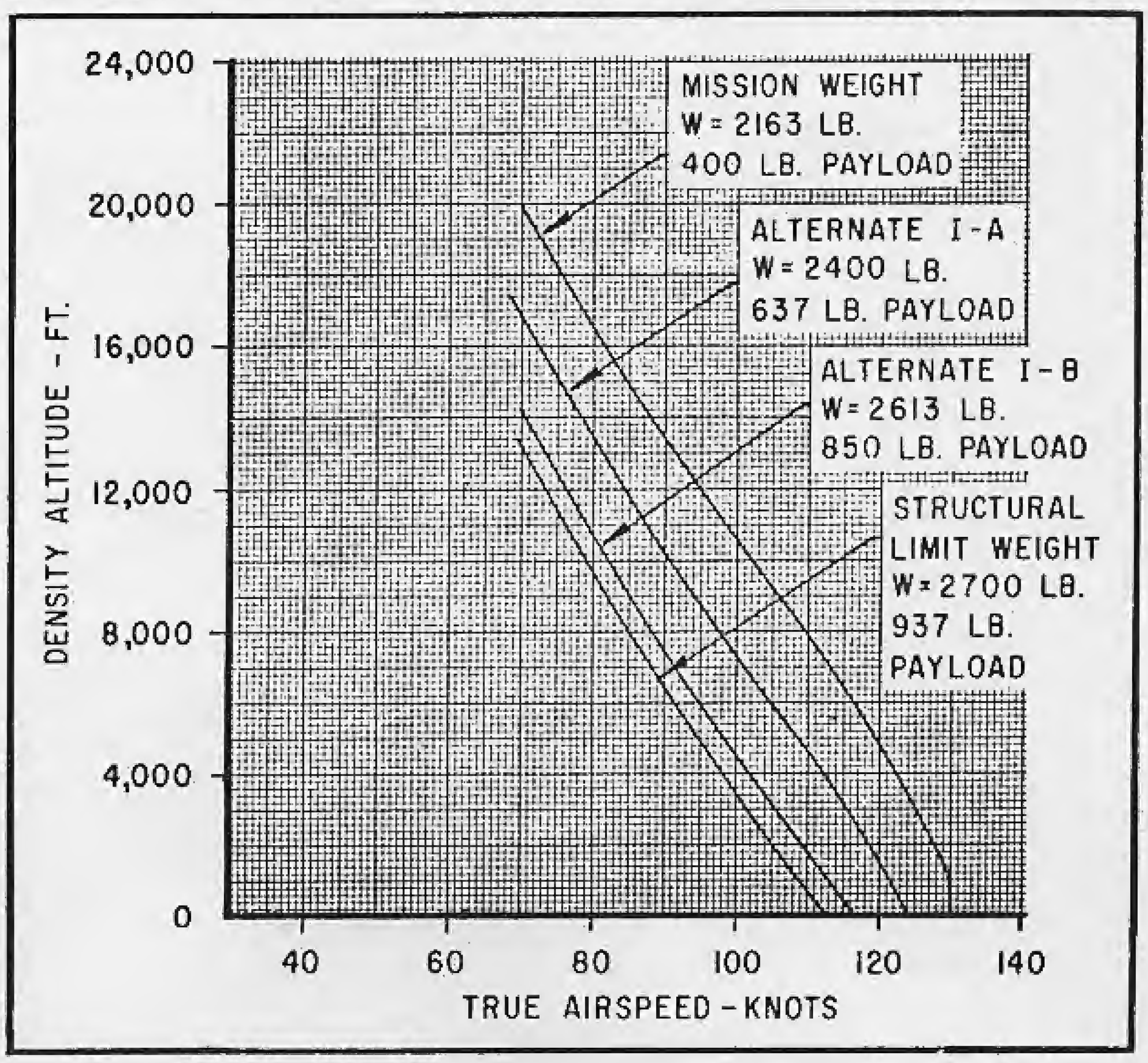
Both civilian LOHs have the same basic airframe as the OH-6A and will all be produced on a common production line. Hughes has set a minimum goal of five Model 500 orders from each dealer before delivery as an incentive for sales. The company reports that several of its 86 dealers already have two or three of the required five orders lined up, but will not provide a total.

Key difference between the OH-6A and Model 500 is in the front compartment. The Model 500 has three seats forward compared with two for the OH-6A. This has been done by eliminating the center pedestal and relocating instruments and switches in a single vertical panel with leg room underneath. The Model 500 is flown from the left seat since the second set of controls is removed to accommodate the middle passenger. Luggage is carried in the rear compartment. Five suitcases may be stowed behind, between and below the two seats, which are hinged to permit easy access.

Flying qualities of the OH-6A were recently demonstrated to Aviation Week & Space Technology on a 40-



CHARTS SHOW PERFORMANCE of Hughes OH-6A at various altitudes, weights and speeds.



min. flight from the Hughes airport here. Observations of this reporter confirmed claims for excellent maneuverability and high performance and, based on limited time at the controls, the aircraft appeared relatively easy to learn to fly.

Chief Engineering Test Pilot Robert G. Ferry, who also is the sole XV-9A hot-cycle helicopter pilot, was host for the flight in N9699F, the fifth OH-6A aircraft built by Hughes. The flight plan, which was closely followed, included demonstrations of a fast startup and takeoff, low-level maneuverability, autorotations, acceleration from hover to 60 kt., terrain following in mountainous areas and landing on sloping terrain.

Pre-Flight Check

Pre-flight checking of the OH-6A amounts to a quick walk around and a check of fuel level and the three sight gages for main and tail rotor gear boxes and engine oil. There are no grease fittings and no hydraulic system.

The aircraft appeared surprisingly simple to pre-flight check and start, and Ferry said this was the reaction of most Army pilots he had checked out in the aircraft. The cockpit is roomy and the forward, centrally located instrument panel is easily visible from the left seat, normally occupied by an observer or copilot. Visibility is good and approximates that of lightweight bubble-canopy helicopters.

Starting Sequence

Starting sequence begins with moving the power selector switch on the center pedestal to battery. The starter button, located on the end of the collective pitch control is depressed and held until idle rpm. of 60% is attained. As engine speed reaches 12-14%, the twist grip is rotated to idle position allowing fuel into the engine. At stabilized idle speed, the collective twist grip is rotated again to full engine rpm. where it remains during the flight.

From the time the starter switch was depressed until the aircraft was hovering 10 ft. in the air, only 39 sec. had elapsed. The Allison T63A-5A turboshaft engine, like other aircraft turbine powerplants, requires no warmup and permits a rapid starting and takeoff.

From hover, the aircraft was accelerated to 60 kt. IAS in 5.5 sec. Later in the flight an acceleration from hover to the same speed was made in 5.2 sec. Takeoff weight for the flight was 1,844 lb., which is lighter than the mission gross takeoff weight of 2,163 lb. with a 400-lb. payload projected for the production OH-6A. Other projected takeoff weights for the production OH-6A include: maximum gross weight of 2,400 lb., overload gross weight with an 850-lb. payload of 2,613 lb. and structural limit weight of 2,700 lb.

The Model 500 will be certified at 2,400 lb. takeoff weight. Federal Aviation Agency type inspection authorization (TIA) for this weight already has been obtained. Hughes obtained an FAA certificate for the OH-6A last June (1964) for a maximum gross takeoff weight of 2,100 lb. Mission weight (400-lb. payload) at that time was 2,080 lb.

Army requirements added since then have increased the wet empty weight from 1,080 lb. to a guaranteed 1,163 lb. (including engine oil) for the production OH-6A. The weight increase came from such things as the addition of self-sealing fuel tanks, increased weight in government-furnished radio equipment and decision to consider copilot controls and rear passenger seats as part of the basic aircraft rather than kit equipment.

Ferry flew the OH-6A around the field for about 15 min., demonstrating turning, climbing and autorotational capabilities of the aircraft. Extremely tight 360-deg. turns which amounted almost to pirouettes were made. In some turns, bank angles up to 90 deg. were reached.

Airspeed for the most part ranged between 90 and 100 kt. Sideways flight at an estimated 40-50 kt. and very rapid 180- and 360-deg. on-the-spot turns during hover appeared as easily done as the other maneuvers, although Ferry's above-average piloting skill may have caused this impression.

Autorotation

Autorotational flight, entered by cutting back the power to idle, was demonstrated several times under different conditions.

The power was chopped during hovering flight at 8-10 ft. and the aircraft settled gently to the ground with what appeared to be more than adequate control power.

At an altitude of 600 ft., the power was again chopped and a 180-deg. descending turn to land into the wind was made. Forward speed of about 60 kt. was maintained and rate of descent appeared to be about 1,500 fpm. Ferry arrested the forward motion prior to touchdown by putting the aircraft in a nose-high attitude, a technique which

Unit Cost of OH-6A to Total $48,000

Unit cost to the Army of the OH-6A without spares and engineering support is expected to be less than $48,000. This includes the Hughes-furnished airframe ($19,860) and two government-furnished items, the engine and avionics package.

The Allison T63A-5A engine will sell for something less than the approximate $13,000 cost of the commercial 250-C18 engine. The avionics package is estimated by Army sources to cost $15,000.

The avionics package (AW&ST Jan. 20, 1964, p. 69), made up essentially of off-the-shelf radio and navigation equipment, ultimately will be replaced with a solid-state group of units providing a considerable weight saving.

No new mission capabilities are expected from the solid-state package which is to be phased into the 257th aircraft. Component packaging will be the primary improvement with the goal of eliminating remote black boxes by incorporating their functions into the control panel unit. This will make only one unit for the average piece of radio gear, which can be easily removed from the cockpit.

The Army is negotiating a contract with Allison Div. of General Motors for the engines and probably will award a contract in early August. The engines will be operated at a flat rating of 250 shp. in the OH-6A and its commercial counterpart, although Allison has improved the engine and applied for FAA certification for a 317-shp. takeoff rating for other applications.

OH-6A Helicopter Estimated Performance

Estimated performance of the Hughes OH-6A light observation helicopter at a mission gross weight of 2,163 lb. follows:

FAA V_{ne}, sea level standard day	130 kt. CAS
Guaranteed	128 kt. CAS.
Maximum rate of climb, military power,	
Sea level	2,120 fpm.
Service ceiling, normal power	18,700 ft.
Hover ceiling, military power, out of ground effect, 95F	5,000 ft.
Range, sea level, 10% reserve	308 naut. mi.
Guaranteed	280 naut. mi.
Maximum endurance, sea level, 10% reserve	3.7 hr.
Guaranteed	3.4 hr.
Best cruise speed for range	118 kt. TAS start, 123 kt. TAS end.

he prefers, and touchdown was made on the rear of the skid landing gear.

The air-oil oleo system absorbed the initial impact without providing a nose-down pitching moment and the helicopter nosed over gently to rest on the skids with no forward motion. The high-mounted tail boom of the OH-6A permits nose-high flareout prior to touchdown without hitting the ground with the tail section, Ferry said. This provides somewhat greater flexibility during the final touchdown and eliminates occasional inadvertent tail-first landings which could result in severing of the tail boom by the main rotor or damage to the tail rotor.

Operating range for the rotor is between 400-514 rpm. and autorotations are normally performed with the rotor turning between 470-485 rpm. at a speed of about 60 kt.

The OH-6A has an unusually high glide ratio, about 6 to 1, at a lower rotor rpm. of 400 and a speed of 80-90 kt. This compares with glide ratio of 4-5 for most helicopters, Ferry said. In a demonstration of glide characteristics from an altitude of about 600 ft. with power in idle, the aircraft floated over a greater distance than previously in a standard autorotational descent, demonstrating an apparently excellent method of stretching a glide to reach a particular landing site. Maintaining minimum rotor speed of 400 rpm. is recommended as a margin for safe energy conversion during landing, although Ferry said he has flown at lower rotor speeds and has never gotten into blade stall problems.

A control unit called a "beeper" is installed to automatically increase engine speed to a rotor rpm. of 103% or 485 rpm. when the power is added from idle rpm.

The power turbine of the free-turbine T63 is linked directly to the rotor through the gear box. Setting the rpm. automatically at 485 ensures best rotor speed if a power recovery is initiated prior to touchdown. The "beeper" unit also allows the pilot to select N_2 rpm. in the 98-104% range, in cruise to gain maximum fuel economy at the lower speeds, although the difference in range is very small. A knurled adjusting handle for the "beeper" is located on the pilot's collective just aft of the twist grip.

In the production OH-6A, the automatic rpm. reset function of the beeper unit probably will be eliminated since Allison has installed a fifth-stage compressor bleed valve to cut engine response time from idle to operating rmp. down to 1½ sec., about half of the former value.

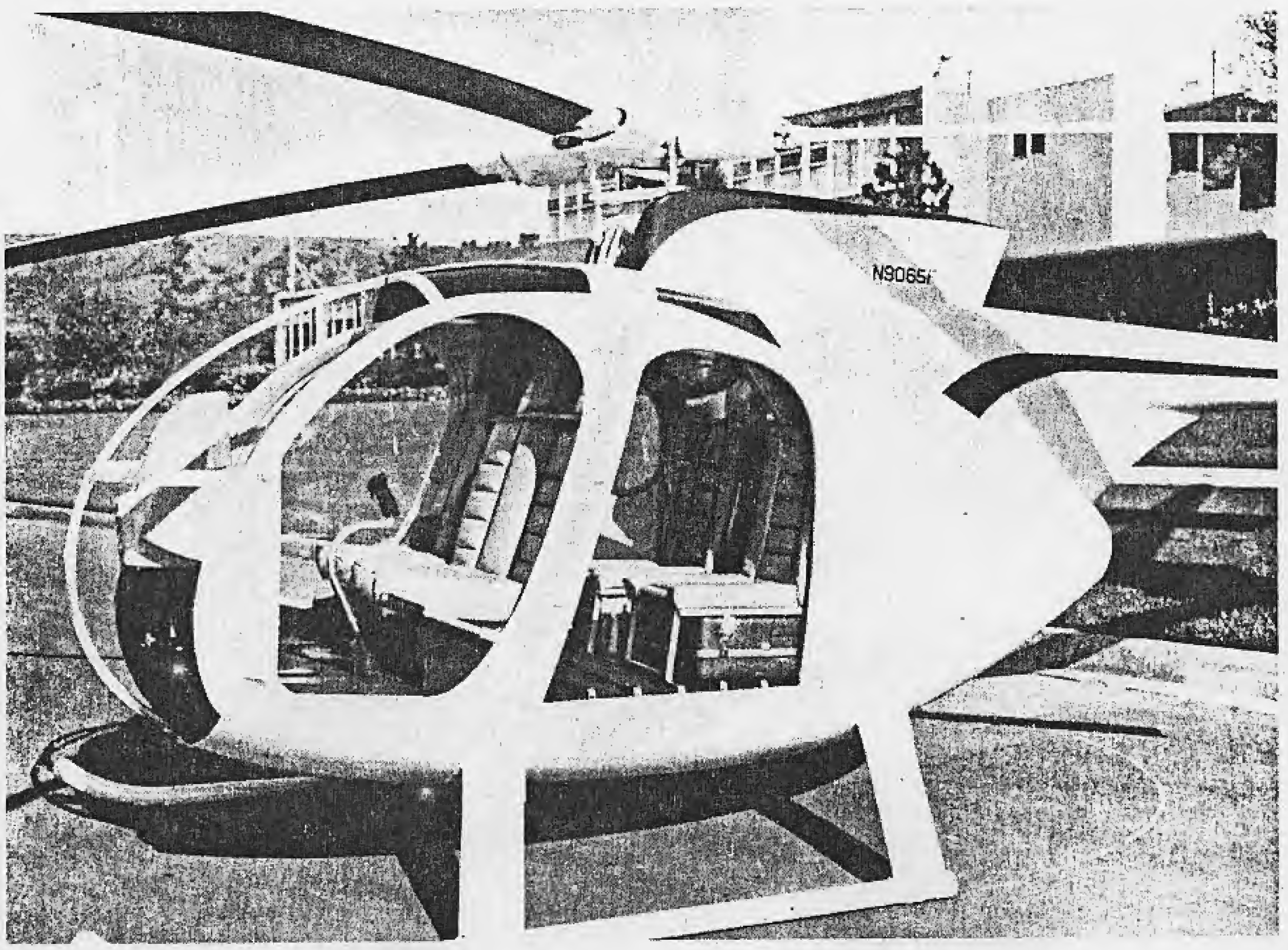
Following the low-level work, the aircraft was flown up the coastline to the company flight test area located in the Santa Monica Mountains about 12 mi. north-northwest of the field. Cruise up the beach to Topanga Canyon, where we headed inland, was at 400 ft. altitude and 122 kt. IAS. Engine torque level was about 73%–91% is maximum.

Ferry landed the aircraft twice on a firebreak along a ridge in the rugged, mountainous area on a slope angled at about 15 deg. Landings were made with first the right and then the left skid touching first, perpendicular to the slope line. The aircraft appeared easy to maneuver on landing and takeoff and no unusual control excursions were necessary.

Landings on slopes as steep as 20 deg. can be made, Ferry said.

A short demonstration of low-level terrain flying was made to simulate the Army's nap-of-the-earth detection-avoidance technique. Again, the high rate of climb and excellent maneuverability indicated that the OH-6A should be well suited for this kind of flying.

For the trip back to the field, Ferry



MOCKUP SHOWS CONFIGURATION of Model 500, civil version of Hughes Tool Aircraft Div.'s OH-6A helicopter.

turned over control of the aircraft to this reporter who flew the aircraft up over the 2,000-ft. mountains, descended to 400 ft. and cruised along the California beach to the Hughes Field entry corridor. Mild turbulence over the mountains had little effect on the aircraft except for an almost undetectable yawing motion.

The cruise home was at redline speed of 126 kt. IAS which was achieved easily with considerable reserve power. The aircraft was steady and easy to trim for level flight with no unusual airframe or control vibrations.

Back at the field, Ferry demonstrated a zoom autorotation maneuver by chopping power at about 115 kt. close to the ground, zooming the aircraft to several hundred feet and autorotating while making a 360 deg. turn to a landing.

Hughes advertises that power can be chopped at high-speed cruise on the deck followed by a zoom to 500 ft. and two 360-deg. turns to an autorotation landing. Ferry said such a maneuver could be accomplished under ideal conditions but felt a little uncomfortable about trying it because of lack of recent flight time in the OH-6A.

After the zoom-autorotation landing, the aircraft was lifted into a hover and the controls again turned over to this reporter who flew around at low level for about 5 min. and landed, completing the demonstration. Ferry carefully monitored the controls but did not find it necessary to take over.

Although an estimated 10-kt. wind was blowing, hovering with nose into the wind was performed acceptably after the function of the "up and down" lever or collective was grasped. Hovering with the tail into the wind proved more difficult and was abandoned in favor of a gentle figure eight.

The OH-6A was easier for this conventional-aircraft pilot to hover than the company's 269A light commercial aircraft. Movement of rudders, stick and collective, which are neither boosted nor augmented, brought positive, quick response but were not overly sensitive. The aircraft felt quite stable without a tendency to oscillate or be skittish, as had been noticeable in the 269.

Landing on the X marking the touchdown point was not difficult and the aircraft was settled gently to the ground evenly on the skids with little difficulty.

The Burns nylon webbing seats proved comfortable during the flight and would appear particularly advantageous in hot weather. The excellent crash characteristics claimed by OH-6A designers were demonstrated during the Army evaluation, according to Ferry, when an OH-6A crashed near Twenty Nine Palms, Calif. The pilot, who had inadvertently flicked off the fuel switch instead of the adjacent master arm switch during recovery from a weapon firing run, found himself in a turn with a dead engine.

In trying to avoid a crowd of troops, the aircraft ran out of lift and crashed in a 38g impact virtually demolishing the OH-6A. Both crewmen survived, however, because of the frangible characteristics of the underside of the aircraft and the A-frame-type construction which kept the cockpit relatively intact, Ferry said.

Since Hughes delivered the OH-6As to Army for evaluation, there have been relatively few modifications to the aircraft and these have been minor, according to Hughes. Typical of these are relocation of the forward canopy brace downward for better visibility and installation of de-fogging outlets in the brace rather than overhead.

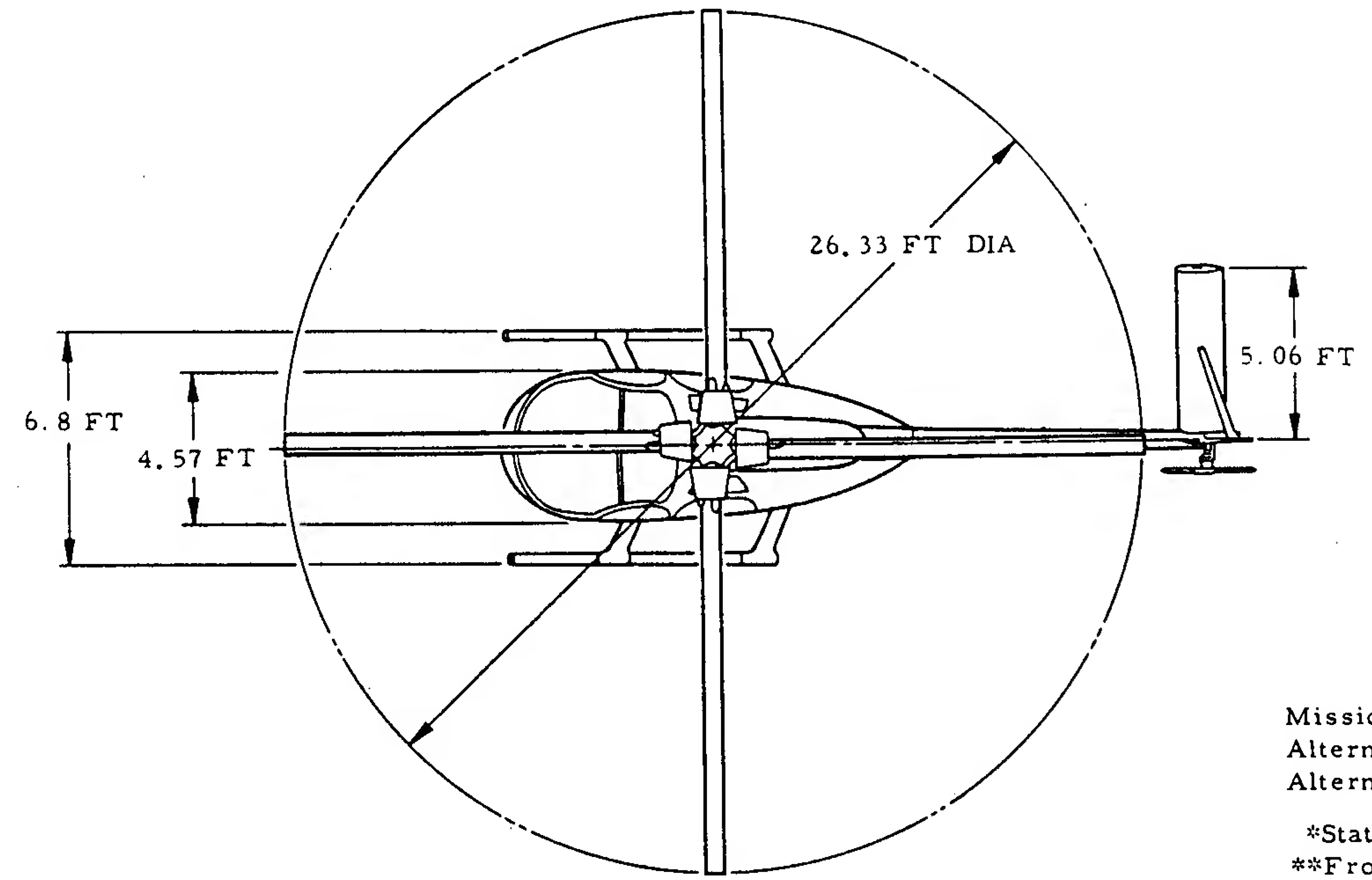
The instrument panel will be reworked according to Army desires and several antennas will be relocated in the production version because of unsatisfactory performances in their original locations in the hub fairing and ventral fin.

Other details now are being worked out to simplify manufacturing and eliminate temporary fixes added in the test program. These include modifying the air intake system and eliminating blade dampers by tuning the blades during fabrication.

Maintainability, a primary goal in design of the OH-6A, has been good, based on testing done so far. In Army maintenance and reliability tests, the OH-6A averaged about 0.8 man hr./flight hr. on a 7-8 hr. per day utilization rate at Ft. Rucker. Hughes has guaranteed a figure of 0.5 man hr./flight hr. for production OH-6As based on three flight hours a day.

The Army will use the OH-6A for visual observation, target acquisition (for ground-based artillery), general reconnaissance and command and control (airborne jeep for command personnel). The aircraft will be assigned to units as small as battalions. Other projected uses include armed escort and suppressive fire missions and expanded utility use down to company level.

Among the weapons which have been fired from the OH-6A are a 40-mm. grenade launcher, 7.26-mm. machine guns and 20-mm. multiple-barrel cannon under development for the Navy by the Aircraft Div.



	Weight	CG Locations Horizontal*	Vertical**
Mission Gross	2163	101.0	50.6
Alternate I-A	2400	99.3	53.0
Alternate I-B	2613	101.1	53.2

*Station 100 is rotor ℄
**From rotor plane

NOTE: ALL DIMENSIONS ARE FOR 2100 LB GROSS WEIGHT

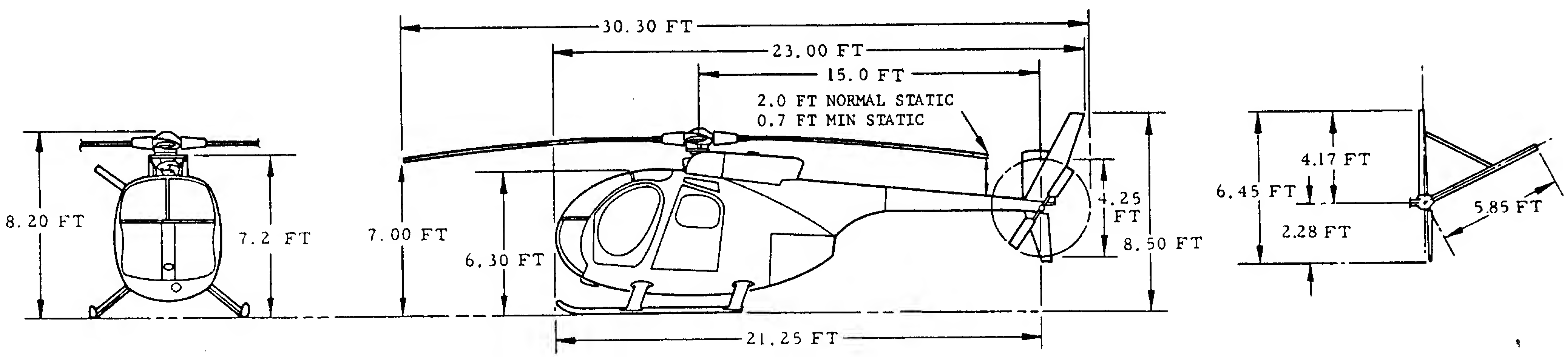


Exhibit B-11 (a): Three View Drawing

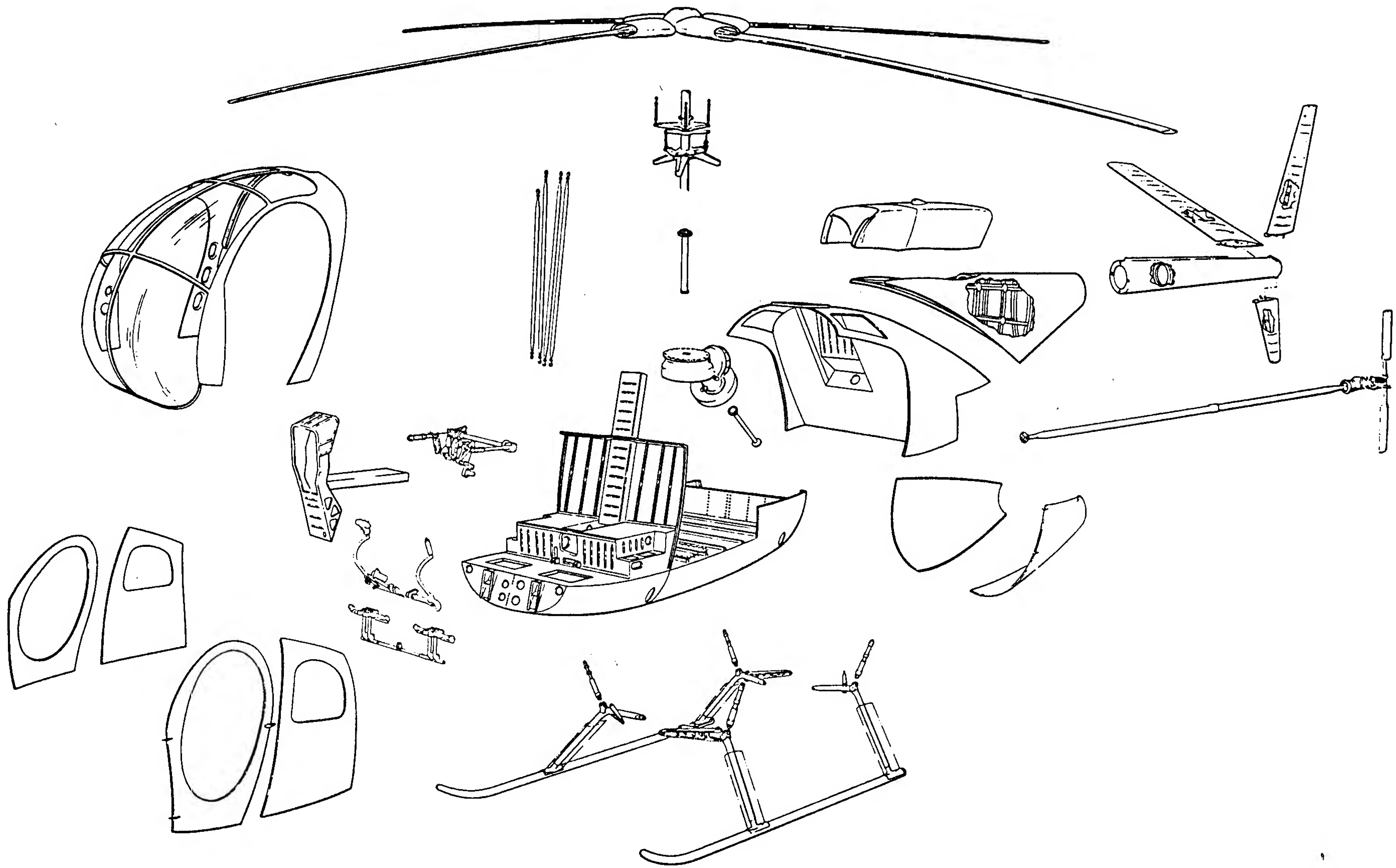


Exhibit B-11 (b): Production Breakdown

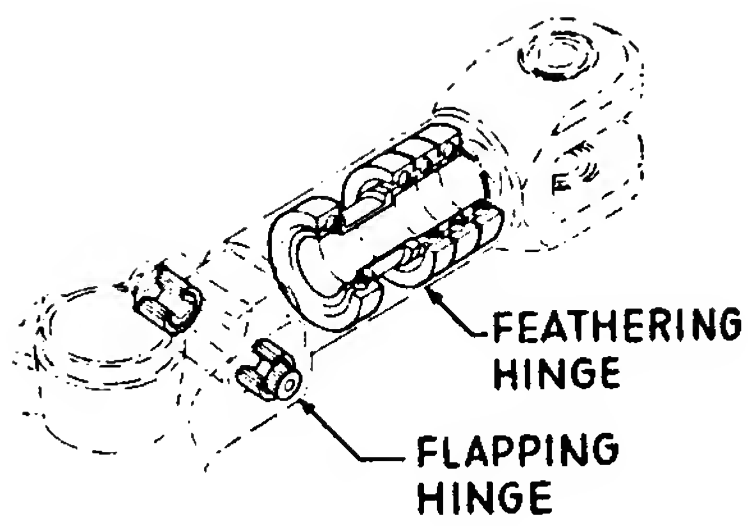


Exhibit B-12 A Typical Bearing System for Rotor Attachment.

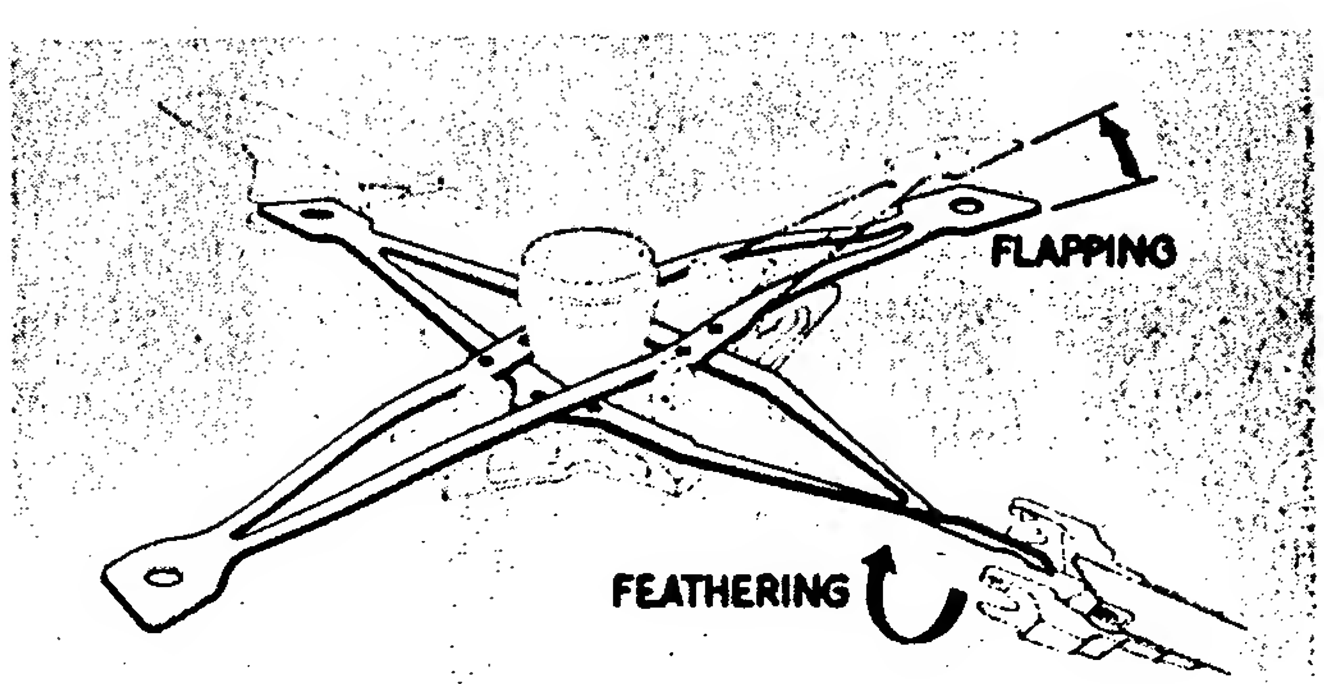


Exhibit B-13 Hughes' Strap Rotor Retention System.

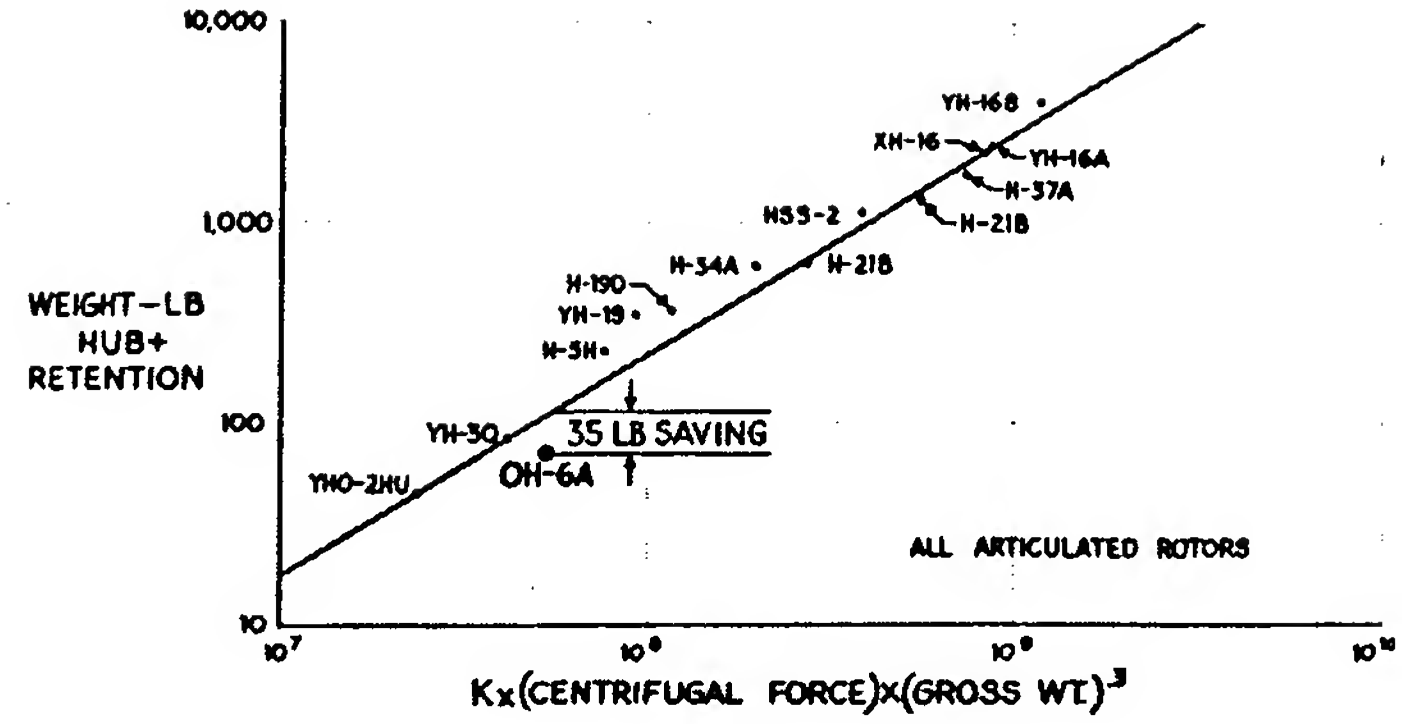


Exhibit B-14 (a) : Weights of Rotor Hubs and Retention Systems for Various Helicopters.

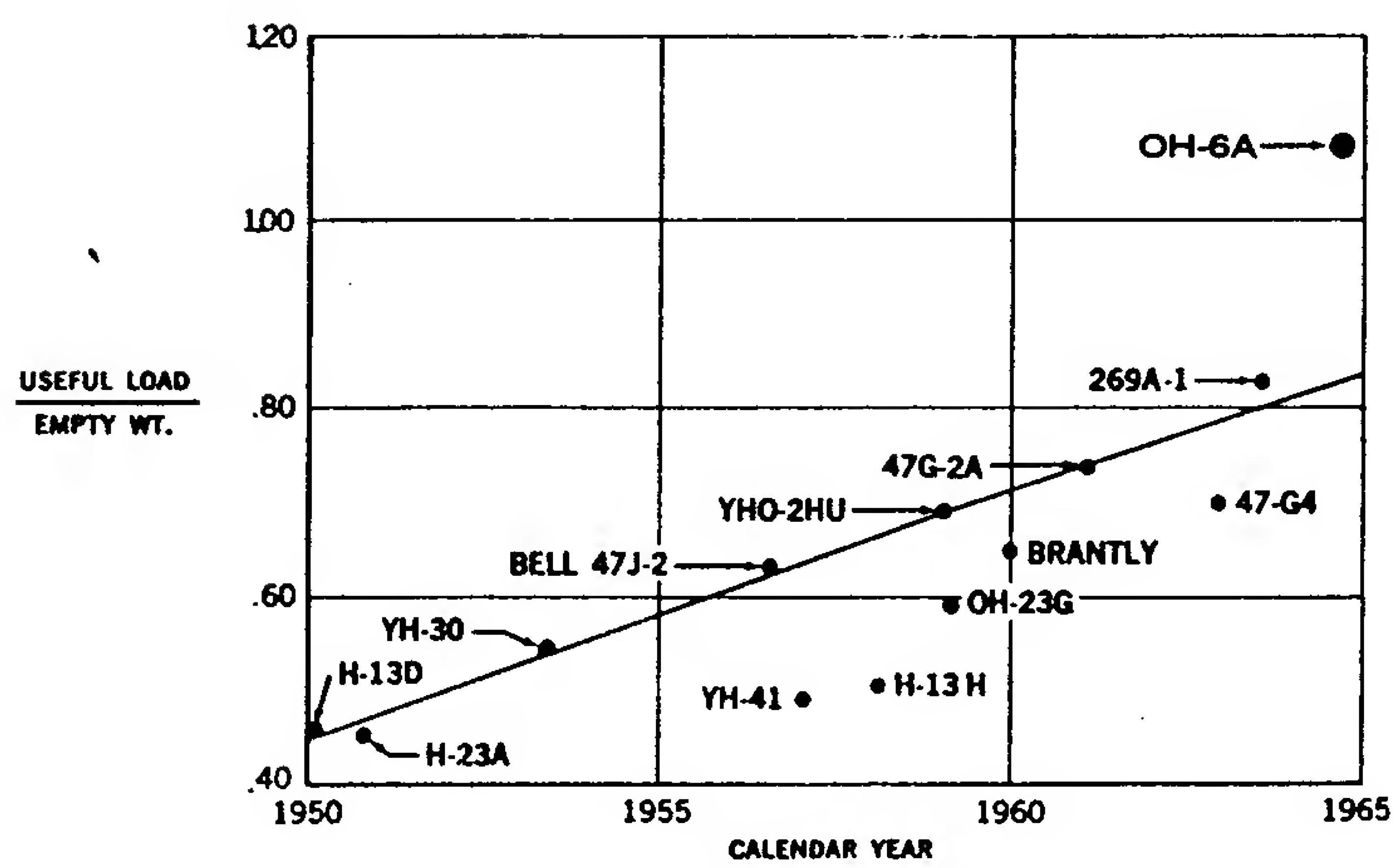


Exhibit B-14 (b) : Weight Efficiency Trend for Helicopters.
(OH-6A is Hughes' LOH)

COMMENTS ON HUGHES TOOL COMPANY HELICOPTER DESIGN CASE

by William Bollay

This story of the development of the Hughes Light Observation Helicopter represents an interesting illustration of how innovation in engineering design is generated in U.S. industry. The intense competition between three competent manufacturers provided the motivating force. The result was a helicopter which was 20 knots (23 mph) faster than that of the nearest competitor. This increased performance was largely due to a program to reduce drag. Hughes' nearest competitor produced an airplane weight of 1200 pounds, 44% heavier than the 830 pound Hughes design. This tremendous weight reduction required both a fundamentally sound philosophy on the arrangement of components and a very persistent campaign on the part of the chief engineer to fight for simplification and a proportional weight reduction of every element. Since aircraft of similar complexity usually cost the same number of dollars per pound, it was clear that in this case weight reduction was also the key to cost reduction.

A major jump in the performance of aircraft occurred in fixed wing aircraft in the early 1930's when the first clean airtransports were developed (Douglas DC2 and DC3). Again a major jump occurred in the early 1940's with the advent of the much lighter turbine engines. Often well-established authorities deride the possibilities of major performance gains. For example, in January 1941, the National Academy of Science prepared a report to the Navy in which they evaluated the possibilities of the gas turbine as follows:

> In its present state, and even considering the improvements possible when adopting the higher temperatures proposed for the immediate future, the gas turbine could hardly be considered a feasible application to airplanes, mainly because of the difficulty in complying with the stringent weight requirements imposed by aeronautics.
>
> The present internal combustion engine equipment used in airplanes weighs about 1.1 pounds per horsepower, and to approach such a figure

with a gas turbine seems beyond the realm of possibility with existing materials. The minimum weight for gas turbines even when taking advantage of higher temperatures appears to be approximately 13 to 15 pounds per horsepower.

It is understood, however, that an appreciable amount of additional structural weight must be incorporated into high-powered aircraft to withstand the severe vibration created by the intermittent torque from the present internal-combustion engines. The gas turbine with its rotary motion and continuous torque may eliminate a considerable amount of this parasitic structural weight and thereby compare somewhat more favorably on a total weight basis.

Notwithstanding this apparent favorable factor, however, it is believed that much additional development work on lighter weight materials with good high temperature properties is still required before the gas turbine can be considered as a serious aspirant in the field of aeronautics.

Despite these pessimistic prognostications the U.S. Navy's Bureau of Aeronautics started the development of axial flow gas turbines and in less than two years had the first engines on static test and in three years in airplanes. Even the first aircraft gas turbines weighed less than the piston engines, and at present they weigh less than 1/3 the weight of piston engines as turbo props, and less than 1/10 the weight of piston engines as turbo jets.

The only general conclusion which the student of engineering can draw from these examples is that in order to accomplish engineering innovation it is essential for an engineer to base his designs upon a philosophy and a design which correctly incorporate the fundamental objectives, and then to persevere and overcome all obstacles which stand in his way. It is more likely a young man, who is not yet completely steeped in the traditions of a given field, who will ask the significant questions and find the unconventional approach to a major engineering innovation.

The Hughes LOH design may be one important step toward a low cost, commercial helicopter. If and when a low cost aircraft gas turbine is developed, the low cost helicopter may have arrived.

Weight reduction by clever design may well be the key to other major innovations in the field of astronautics. For example, electrical propulsion systems promise a reduction by a factor of 10 in the propellant required for interplanetary space transport. However, the very high weight of the electric power generator system makes electrical propulsion not competitive. A weight reduction in this element would make space transportation between the planets a much more practical possibility.